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NEVADA TEST SITE
RADIONUCLIDE INVENTORY AND DISTRIBUTION PROGRAM: REPORT #2. AREAS 2 AND 4

by

Richard D. McArthur

and

Joseph F. Kordas

September 1985

WATER RESOURCES CENTER

Publication # 45041

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ABSTRACT

Radionuclide activity was measured by *in situ* spectrometry at 349 locations in Areas 2 and 4 of the Nevada Test Site. The data were analyzed by kriging and other methods to estimate the total inventory and distribution of six man-made radionuclides that were present in measurable amounts. Isotope ratios in soil samples were then used to infer the inventories of three other radionuclides. The estimated inventories were: ^{241}Am, 8 curies; ^{238}Pu, 18 curies; $^{239,240}Pu$, 51 curies; ^{60}Co, 7 curies; ^{137}Cs, 34 curies; ^{90}Sr, 71 curies; ^{152}Eu, 35 curies; ^{154}Eu, 6 curies; and ^{155}Eu, 3 curies.

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NEVADA TEST SITE
RADIONUCLIDE INVENTORY AND DISTRIBUTION PROGRAM:
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INTRODUCTION

The Radionuclide Inventory and Distribution Program (RIDP) is a five-year project to determine the total amount and the distribution of man-made radionuclides in the surface soil of the Nevada Test Site. The Test Site is so large (about 1,350 sq mi or 3,500 sq km) that the program cannot rely only on laboratory analysis of soil samples to provide the necessary data. Instead, it uses aerial surveys for an overall picture of radionuclide distributions and *in situ* spectrometry for detailed information about specific areas such as the ground zeros (GZs) of atmospheric nuclear tests. With this combination of methods, the RIDP expects to complete its inventory and distribution studies by the end of 1986.

The program's strategy is to first identify areas of high activity from an aerial survey of external exposure rate. Sampling points for these areas are then selected, and a spectrum of the gamma radiation given off by radionuclides in the soil is recorded at each sampling point. Several soil samples are also collected in each area and analyzed to determine radionuclide distributions with depth in the soil and to measure radionuclides that do not emit strong gamma rays. Parameters computed from the soil measurements are used to calculate radionuclide activities from the gamma-ray spectra, and the activity data are then analyzed statistically to estimate the total inventory and distribution of each radionuclide.

TABLE 1. ATMOSPHERIC NUCLEAR TESTS IN AREAS 2 AND 4

Event	Date	Location	Yield (kT)	Nevada Grid Coordinates	
Area 2					
Diablo	7/15/57	T-2b	17	E662634	N874146
How	6/05/52	T-2	14	E659989	N869835
Badger	4/18/53		23	E659989	N869835
Turk	3/07/55		43	E660058	N869840
Whitney	9/23/57		19	E660103	N869823
Shasta	8/18/57	T-2a	17	E663323	N866030
Area 4					
Fox	5/25/52	T-4	11	E664462	N854233
Nancy	3/24/53		24	E664462	N854233
Apple I	3/29/55		14	E664462	N854233
Kepler	7/24/57		10	E664462	N854233
Ray	4/11/53	T-4a	0.2	E667452	N855494

and north of an arbitrary reference point. For convenience, the two GZs at which several tests occurred will be referred to as Whitney and Kepler.

Figure 1 shows the exposure rate isopleths in Areas 2 and 4 produced by Fritzsche (1982) from a 1978 aerial survey of Yucca Flat. These isopleths were used as the basis for selecting 349 *in situ* measurement locations in a 21.5 sq mi region surrounding the five GZs (Figure 2). The dashed lines in Figure 2 show how the region was partitioned into smaller areas when the inventories were estimated. The Kepler area is in Area 4, while the Shasta, Whitney, and Diablo areas are in Area 2.

The measurements were made with a high-purity germanium detector suspended above the ground. During each 15-minute measurement period, pulses from gamma rays reaching the detector were fed into a pulse-height analyzer and sorted to produce an energy spectrum. At the end of the measurement, the spectrum was stored on magnetic tape and sent to LLNL, where the computer package GAMANAL (Gunnink and Niday, 1971) was used to analyze the spectrum and convert the raw counts per minute data to estimated activities (in nCi/m^2) for each radionuclide.

Most of the measurements were made between October 1981 and June 1982, although 18 points along the eastern edge of the region were sampled in October 1982.

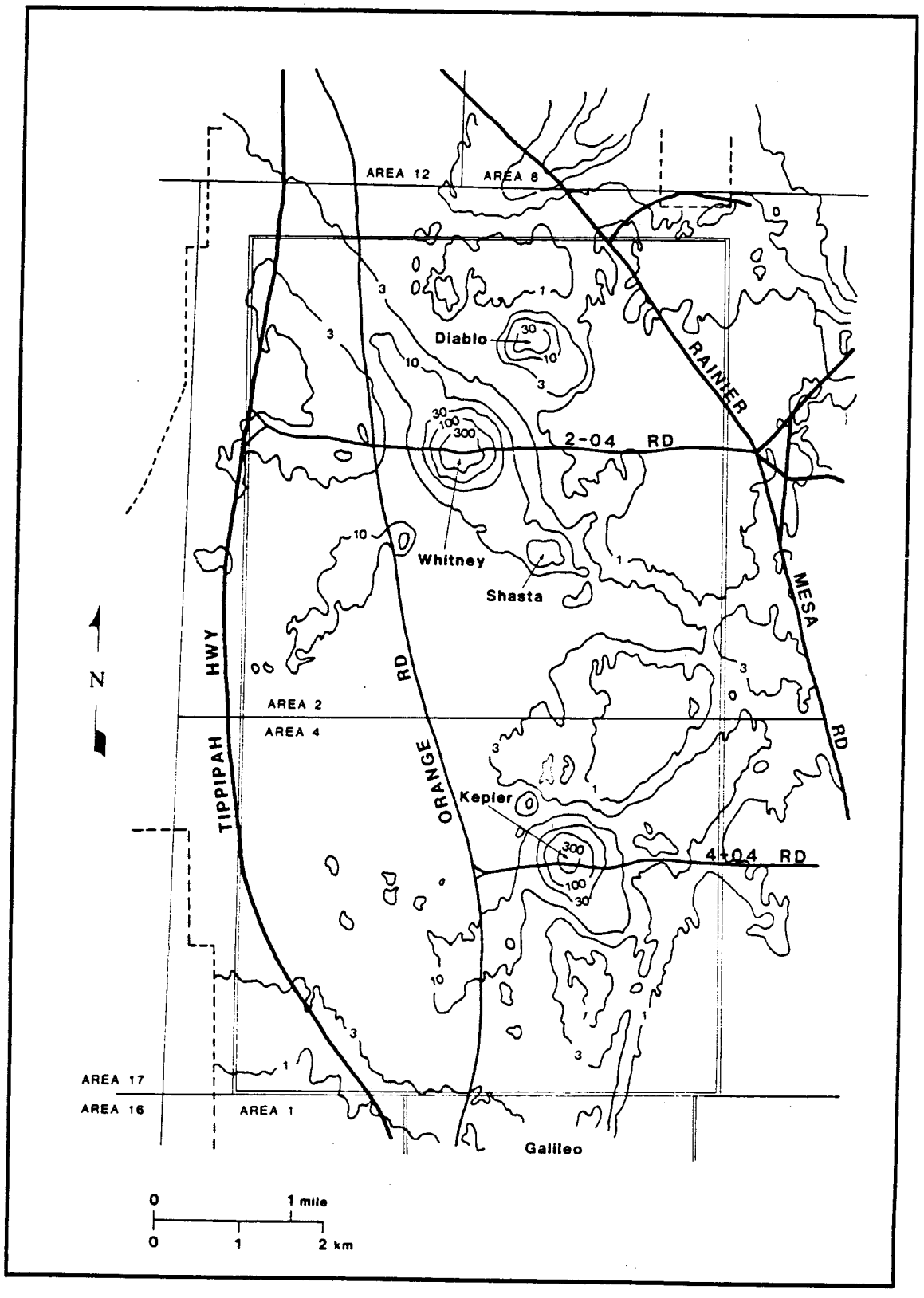


Figure 1. Exposure rates (μR/hr) in Areas 2 and 4. The double rectangle shows approximately the region covered in this report. (From a map produced for the U.S. Department of Energy by REECo.)

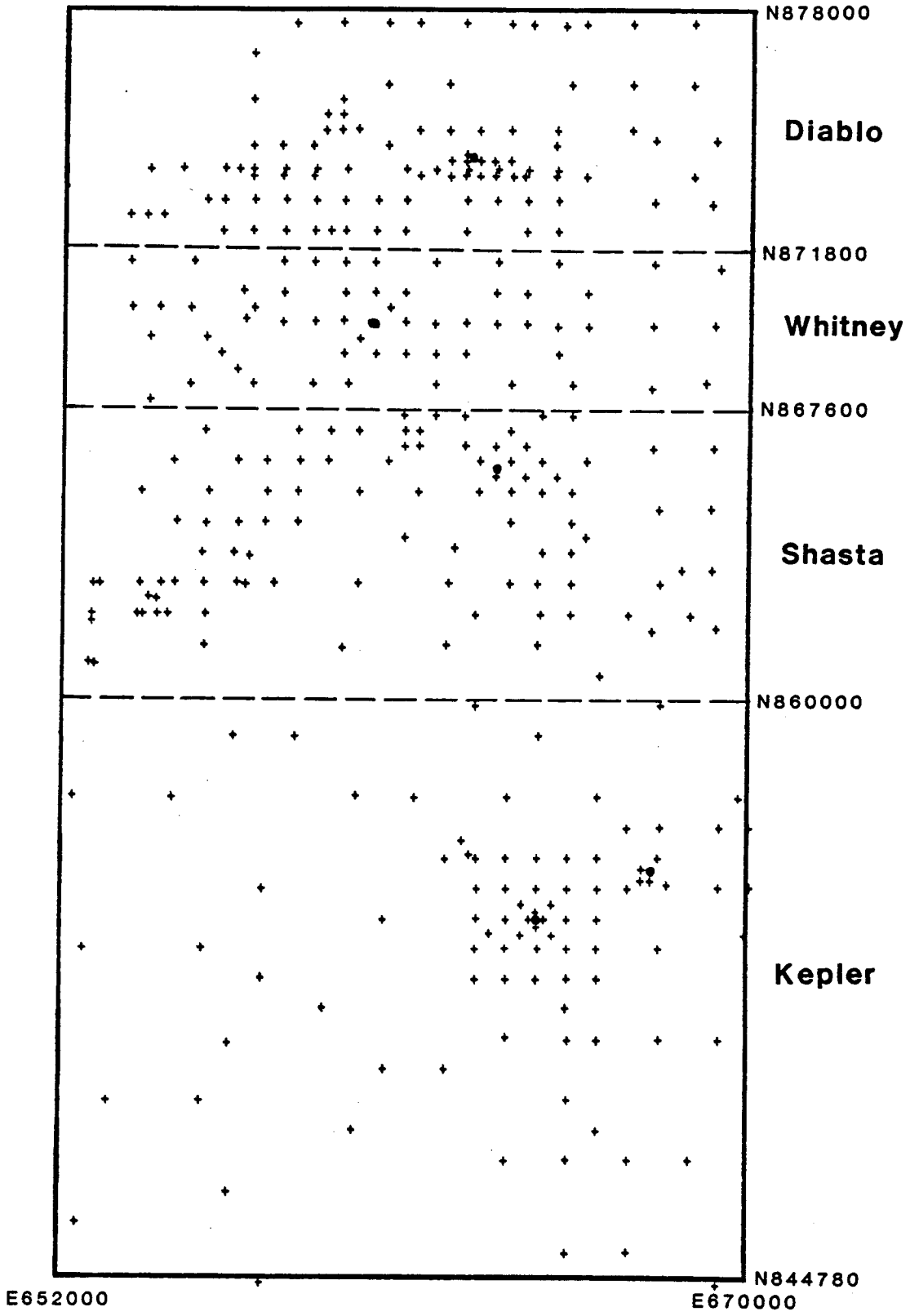


Figure 2. Locations of *in situ* measurements in Areas 2 and 4. The dashed lines indicate the partitioning of the region into four areas for inventory estimation.

● = ground zero

Nine points in the SW corner of the Shasta area were measured in June 1983 after initial measurements showed unexpectedly high activity there.

SOIL ANALYSES

The 38 locations at which soil samples were collected are shown in Figure 3 and listed in Appendix A. At each location, samples were taken in four increments to a total sampling depth of 15 cm. Each sample was oven-dried, homogenized with a ball mill, and sieved through a 10-mesh screen before analysis.

Radionuclide concentrations in the fine fraction of the soil samples, as measured by gamma-ray spectroscopy at LLNL and the REECo Analytical Laboratory, are given in Appendix B. If the concentration is assumed to vary exponentially with depth in the soil, the depth distribution can be parametrized by the inverse relaxation length in cm^{-1}. Table 2 gives the inverse relaxation lengths computed from the data in Appendix B by the methods described in McArthur and Kordas (1983).

The fine fraction of the top increment from several locations was analyzed for plutonium and strontium by the REECo laboratory. Table 3 gives the results of these analyses. The ratios in this table were used to infer inventories of plutonium and strontium from the estimated ^{241}Am and ^{137}Cs inventories.

The parameters used to compute the factors for converting photopeak counts to radionuclide activities are summarized in Table 4. For some radionuclides, the inverse relaxation lengths used for points near the GZs differed from those used for points farther away. The points considered "near" the GZs are outlined in Figure 3. The mass attenuation coefficients for all energies of interest were obtained by interpolation from Beck *et al.* (1972).

Appendix C describes a quality assurance study that confirms the validity of the radiochemical and spectroscopic analyses of the soil samples.

INVENTORY AND DISTRIBUTION ESTIMATES

In Situ Measurements

The results of the *in situ* measurements of six radionuclides are plotted in Figures 4 through 9. These six were the only man-made radionuclides found at measurable levels, although trace amounts of ^{133}Ba were reported from several points near the eastern edge of the area. Results are shown as "none detected" (n.d.) when the gamma-ray spectrum did not contain the peaks associated with a particular radionuclide. Such results were actually reported as "upper limit values" calculated from the background levels in the

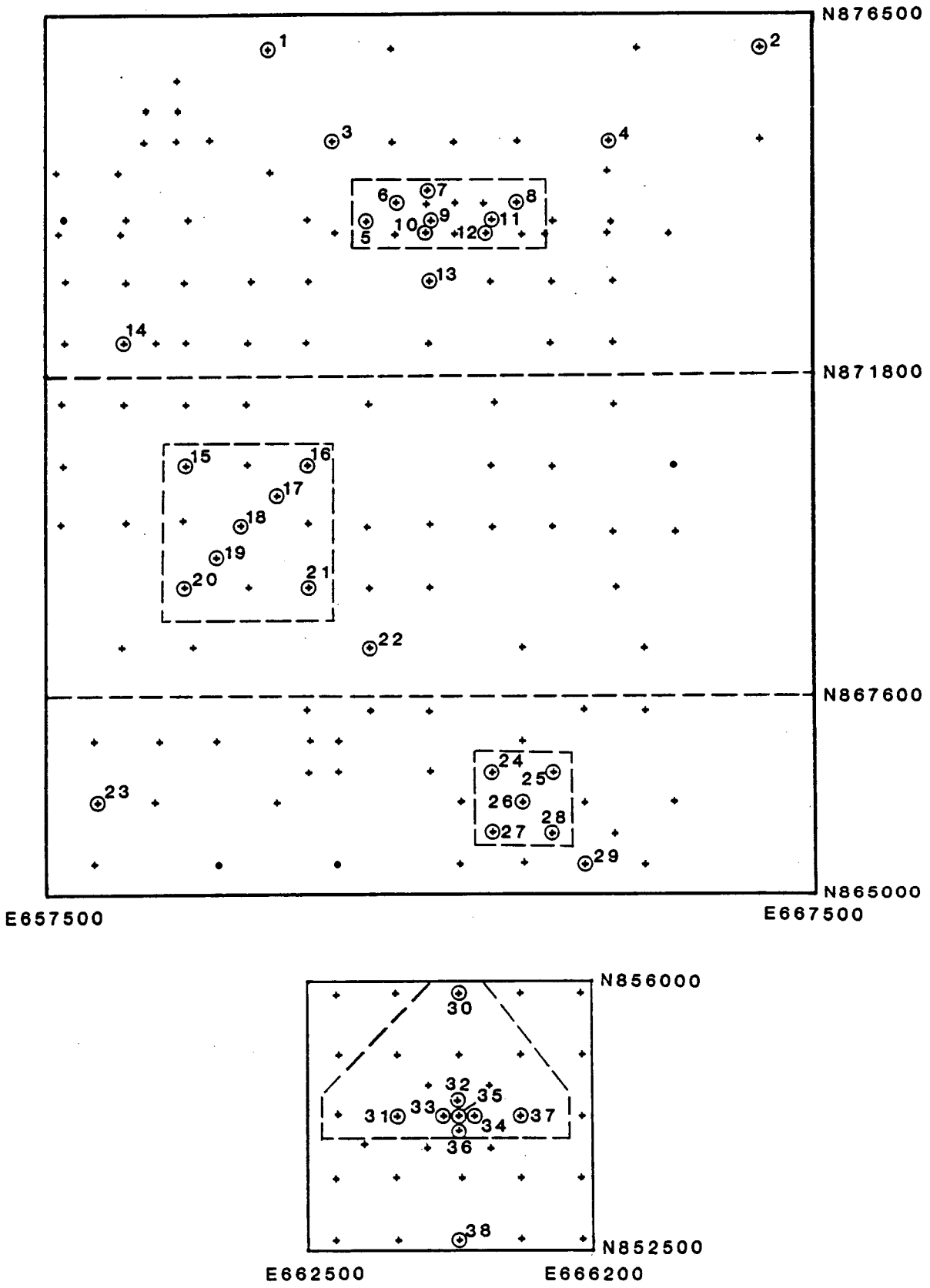


Figure 3. Locations of soil samples. The dotted lines enclose the points considered "near" the ground zeros when choosing an inverse relaxation length (see Table 4).

TABLE 2. CALCULATED INVERSE RELAXATION LENGTHS

Point	Inverse relaxation length ($\bar{cm}^{-1}$ ± 1 s.d.)					
	^{60}Cs	^{137}Cs	^{152}Eu	^{154}Eu	^{155}Eu	^{241}Am
3	----[+]	0.43 ± 0.09	----	----	----	----
4	----	0.27 ± 0.03*	----	----	----	----
5	0.16 ± 0.02*	0.41 ± 0.16	0.12 ± 0.02	----	0.067 ± 0.044	----
6	0.33 ± 0.07	0.31 ± 0.06	0.12 ± 0.06*	----	0.34 ± 0.08	0.34 ± 0.06
7	0.080 ± 0.014*	0.19 ± 0.03	0.062 ± 0.005*	----	0.14 ± 0.03	0.19 ± 0.05

TABLE 3. RADIONUCLIDE CONCENTRATIONS AND RATIOS IN SOIL SAMPLES

		Concentration (pCi/g)*					Ratio		
Area	Point	$^{239,240}Pu$	^{238}Pu	^{241}Am	^{137}Cs	^{90}Sr	$^{239,240}Pu/Am$	$^{238}Pu/Am$	Sr/Cs
Diablo	6	340	160	82	320	550	4.1	2.0	1.7
	9	61	28	9.1	43	100	6.7	3.1	2.3
	11	83	39	14	49	110	5.9	2.8	2.2
	12	160	80	28	120	230	5.7	2.9	1.9
							Mean: 5.6	2.7	2.0
Whitney	17	150	26	9.3	90	310	16	2.8	3.4
	18	240	140	35	320	330	6.9	4.0	1.0
	19	190	53	17	130	380	11	3.1	2.9
	21	94	23	7.2	73	290	13	3.2	4.0
							Mean: 12	3.3	2.8
Shasta	24	46	17	4.8	31	82	9.6	3.5	2.6
	26	180	79	24	120	340	7.5	3.3	2.8
	28	26	11	4.8	20	49	5.4	2.3	2.4
							Mean: 7.5	3.0	2.6
Kepler	32	110	--	16	42	66	6.9	--	1.6
	33	560	--	190	420	400	2.9	--	0.95
	35	1600	--	230	520	590	7.0	--	1.1
	36	540	150	76	290	410	7.1	2.0	1.4
							Mean: 6.0	2.0	1.3

* Most concentration values are an average of several measurements.

TABLE 4. PARAMETERS USED TO COMPUTE CONVERSION FACTORS

Air density	0.001204 g/cm^3
Soil wet density	1.5 g/cm^3
Soil moisture	10%

Examples of mass attenuation coefficients (cm^2/g)

	Air	Soil
60 keV	0.177	0.248
662 keV	0.0770	0.0781
1332 keV	0.0550	0.0558

Inverse relaxation lengths (cm^{-1})

^{241}Am	0.8	(0.6 near the Kepler GZ)
^{60}Co	0.4	(0.1 near the Whitney GZ)
^{137}Cs	0.4	
^{152}Eu	0.3	(0.05 near the GZs)
^{154}Eu	0.3	(0.05 near the GZs)
^{155}Eu	0.6	

region of the spectrum where the peak should have been.

There is no entirely satisfactory method of dealing with upper limit values in the data. They are clearly less reliable than the other measurements, yet they do provide information that should not be ignored completely. When these data were analyzed, the upper limit values were not treated differently from the other data except as described below.

Inventory Estimates

Methods

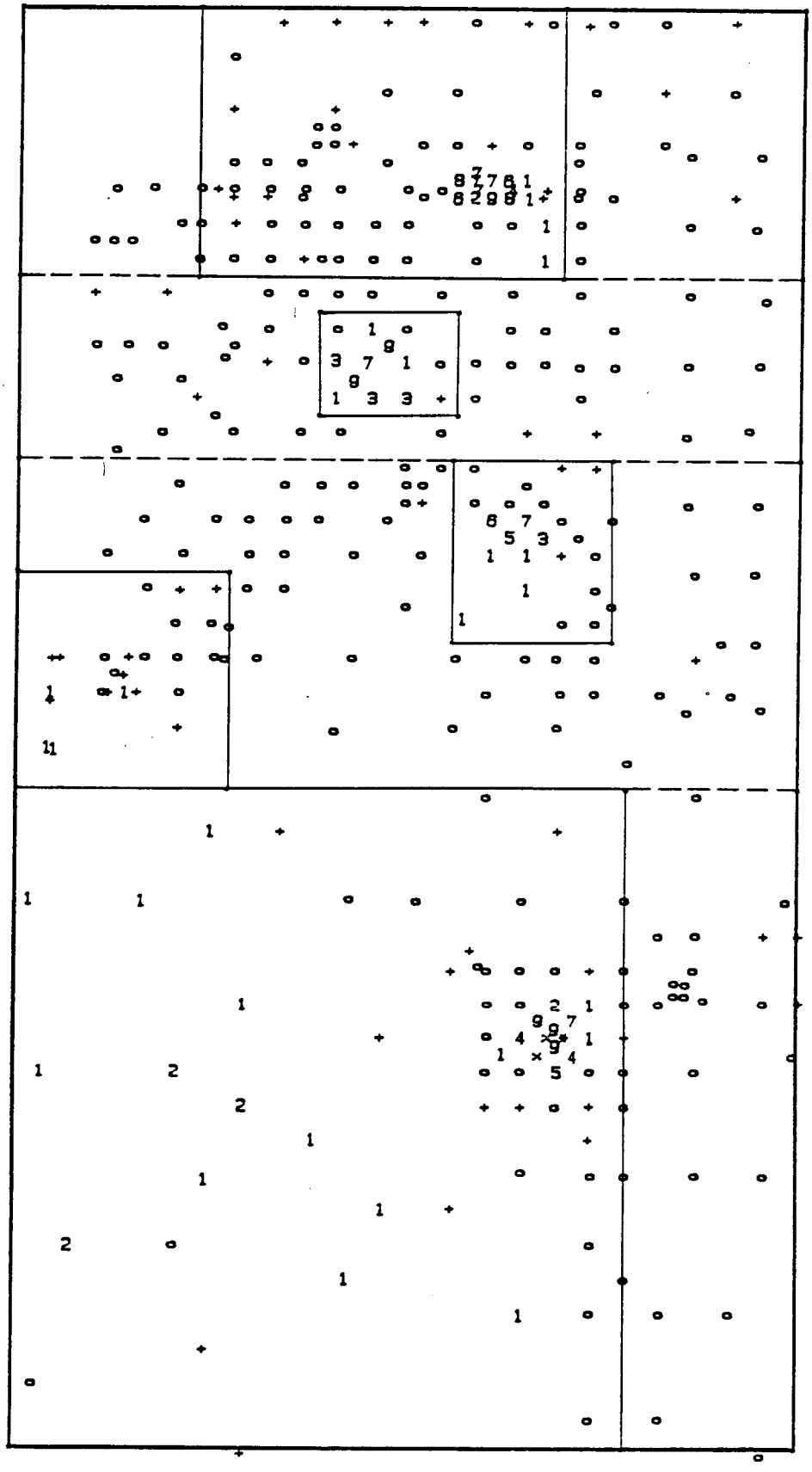
The estimation of radionuclide inventories was complicated by the limitations of the kriging program (BLUEPACK; Delfiner *et al.*, 1978) and by the presence of large areas in which only upper limit values were reported. The procedure was as follows:

1. Because BLUEPACK can handle at most 100 data points when estimating the average over a territory, the data were first divided into four sets corresponding to the four areas indicated by the dashed lines in Figure 2. The data from each area were then analyzed separately.
2. For each radionuclide, one or more rectangular regions (shown by solid lines in Figures 4 through 9) were defined in each area to include most of the points at which the radionuclide was found at levels above the detectable minimum. The inventory within each of these regions (the "above-background" regions) and outside them (the "background" region) was estimated separately.

Inventories in the background regions were estimated by computing the arithmetic mean of the data in each region, then multiplying the mean (nCi/m^2) by the area (ft^2) and the conversion factor (9.29×10^{-11} m^2Ci/ft^2nCi). Because most of the data in these regions are upper limit values, the estimated inventories are presumably higher than would have been obtained from more accurate measurements.

This straightforward estimation method is less suitable for the above-background regions, where the concentration of sampling points near the GZs makes the arithmetic mean of the data a very biased estimate of the true mean. The estimates in these regions were based on kriging, a geostatistical estimation method that takes into account the relative locations of the data points (Journel and Huijbregts, 1978).

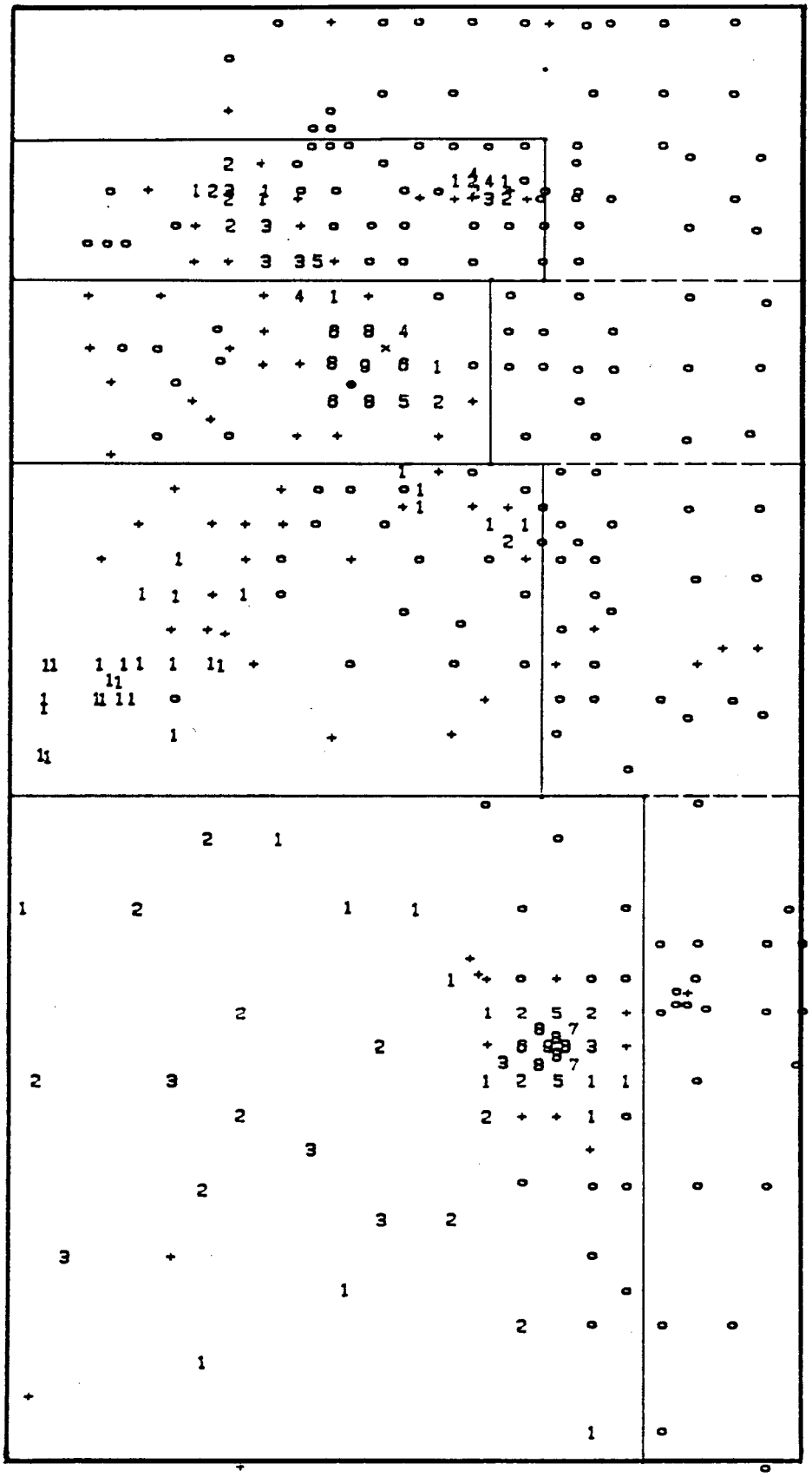
Use of kriging requires an estimate of the variogram, a function which describes the covariance structure of the data. Sample variograms were computed with the GAMMA program of Chiles (1975) from the above-background data only, since including the relatively constant upper limit values from background regions would make the



^{241}Am (nCi/m^2)

o	n.d
+	<100
1	100-200
2	200-300
3	300-400
4	400-600
5	600-800
6	800-1000
7	1000-1500
8	1500-2000
9	2000-3000
x	3000-4000
*	5640

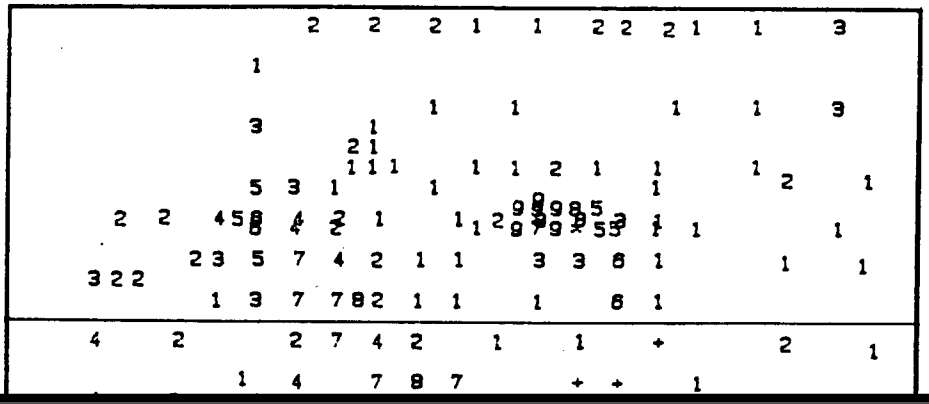
Figure 4. Measured ^{241}Am activities.



^{60}Co (nCi/m^2)

o	n.d
+	<100
1	100-200
2	200-300
3	300-400
4	400-600
5	600-800
6	800-1000
7	1000-2000
8	2000-3000
9	3000-4000
x	4720
*	7770

Figure 5. Measured ^{60}Co activities.



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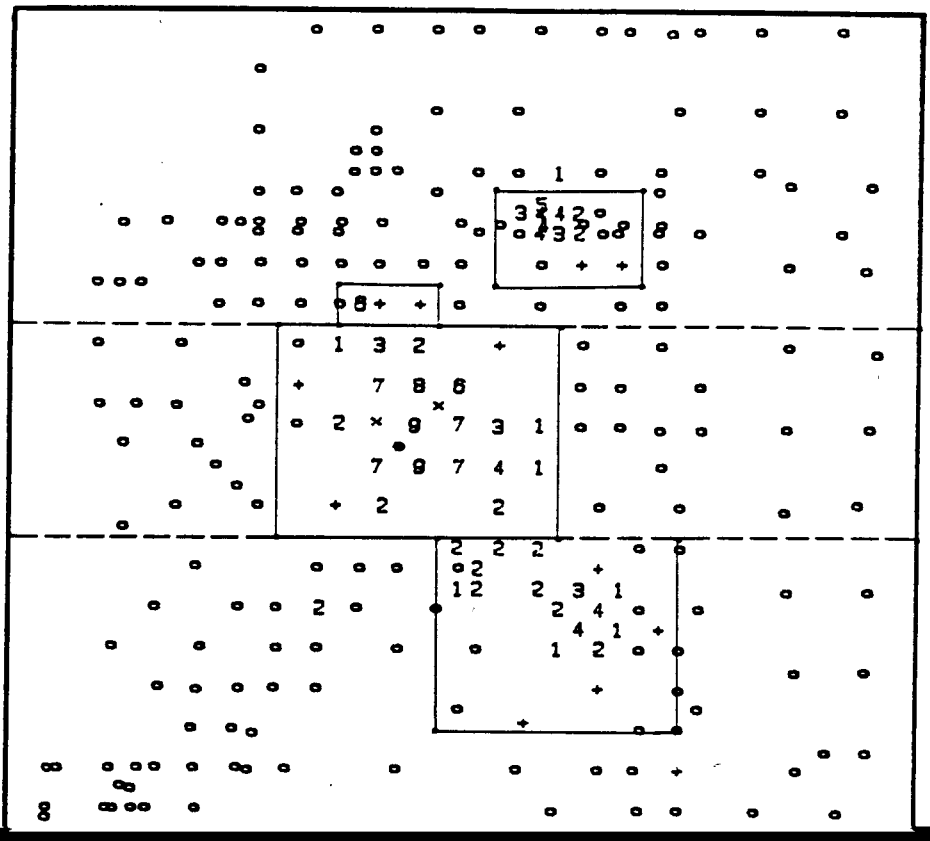

^{152}Eu (nCi/m^2)

o	n.d
+	<100
1	100-200
2	200-500
3	500-1000
4	1000-2000
5	2000-5000
6	5000-10,000
7	10,000-20,000
8	20,000-40,000
9	40,000-50,000
x	50,000-100,000
*	100,000-136,000

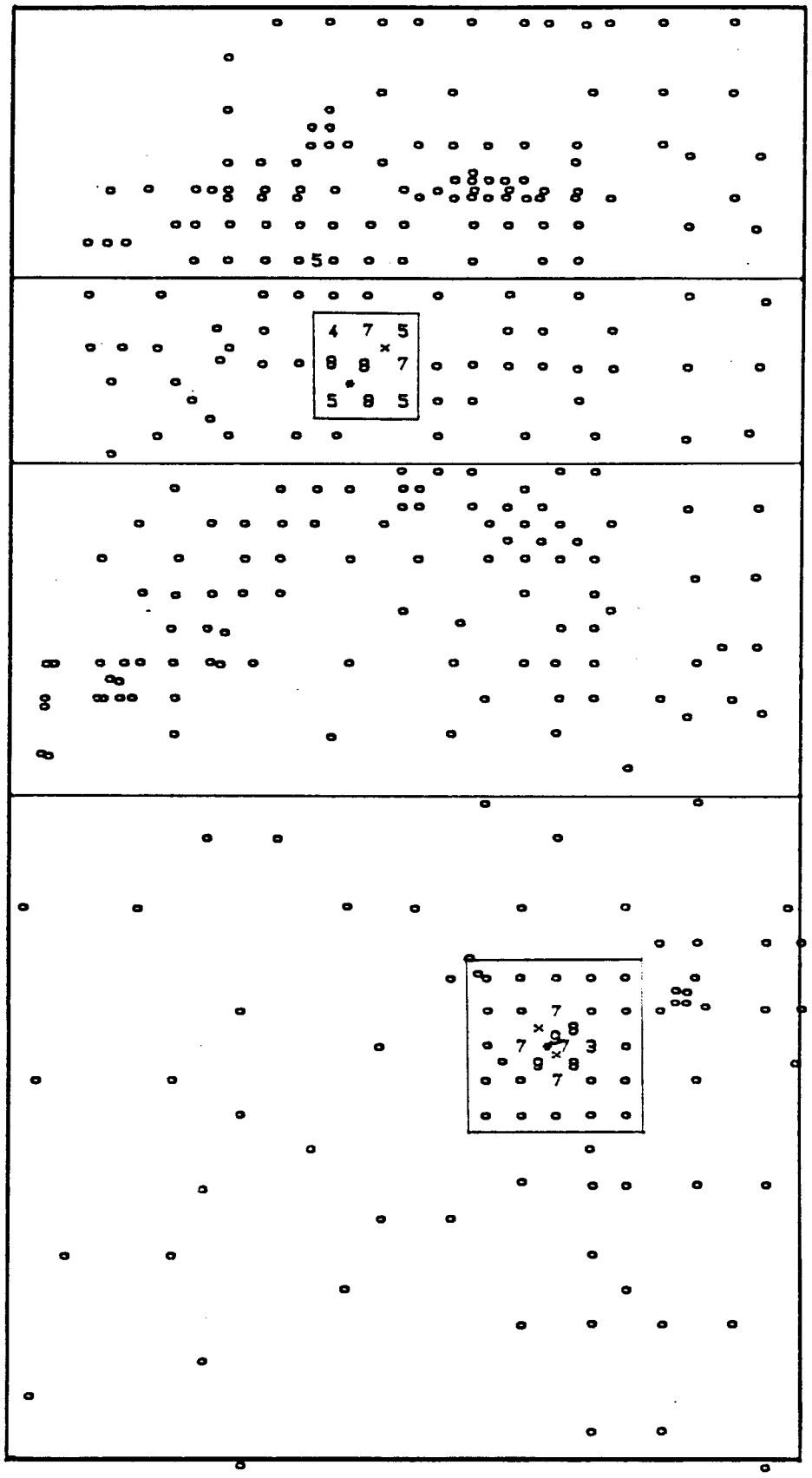

Figure 8. Measured ^{154}Eu activities.

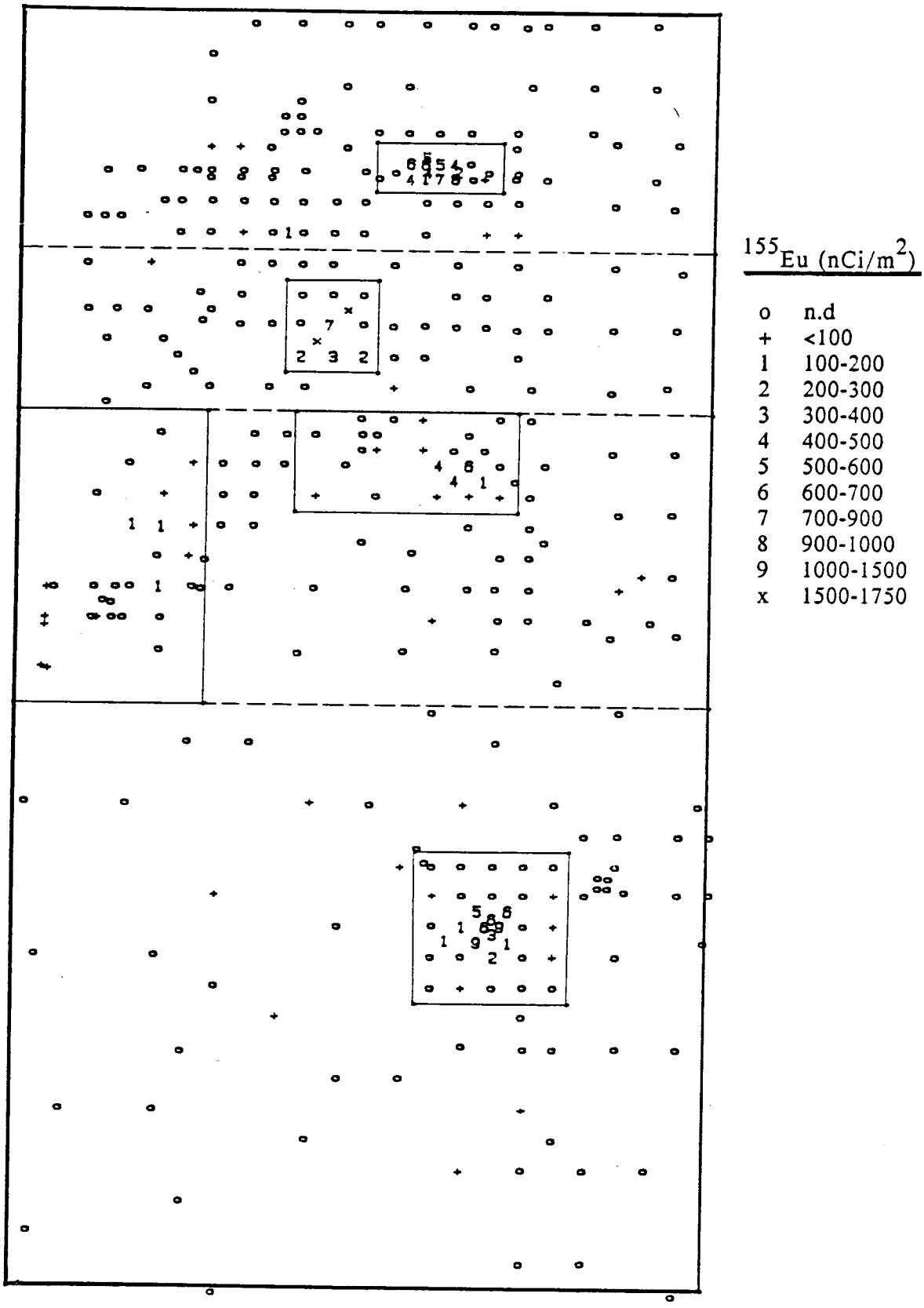

Figure 9. Measured ^{155}Eu activities.

activity appear less variable than it actually is. A sample variogram was not computed for ^{154}Eu, which was present at measurable levels at only 24 points. Sample variograms for the other five radionuclides are shown in Figure 10.

The sample variograms are all characterized by large fluctuations, and fitting a smooth model to them with any degree of confidence is difficult. In all five cases the fitted curve is a spherical model, which expresses the variability between measurements at points separated by a distance h as a function of h and three parameters:

- the nugget effect, the variance of repeated measurements at the same point;
- the range, the distance beyond which measurements are independent; and
- the sill, the value of the variogram as h goes to infinity.

The parameter values used are summarized below.

	nugget	range (ft)	sill
^{241}Am	30,480	400	1,130,480
^{60}Co	57,000	1,500	657,000
^{137}Cs	48,000	500	6,048,000
^{152}Eu	2.7×10^7	1,200	8.27×10^8
^{155}Eu	46,000	600	120,000

The nugget effect was estimated from the data at 17 points where repeat measurements were made. (The average values at these points were used in all subsequent computations.) The other two parameters were chosen to give a curve which seemed to fit the sample variogram reasonably well, keeping in mind that the sample variograms are biased upward from the concentration of data points in regions of rapidly changing activity.

Once the variogram models were chosen, the "Territory" option of BLUEPACK was used to estimate the average activity in the above-background regions in each area. All the data were used in these computations. For example, in estimating the above-background ^{241}Am inventory in the Whitney area, all 59 data values (including the many upper limit values) were included in the BLUEPACK input file. However, by suitably choosing the parameters of the BLUEPACK run, the average activity was estimated only in the small region around the GZ (Figure 4).

The use of kriging assumes that the average level of activity is constant over the territory being estimated. (In statistical terms, the observed radionuclide distribution is assumed to be a realization of a stationary random function.) This assumption is highly questionable when radionuclides are locally concentrated around a GZ, and it is therefore

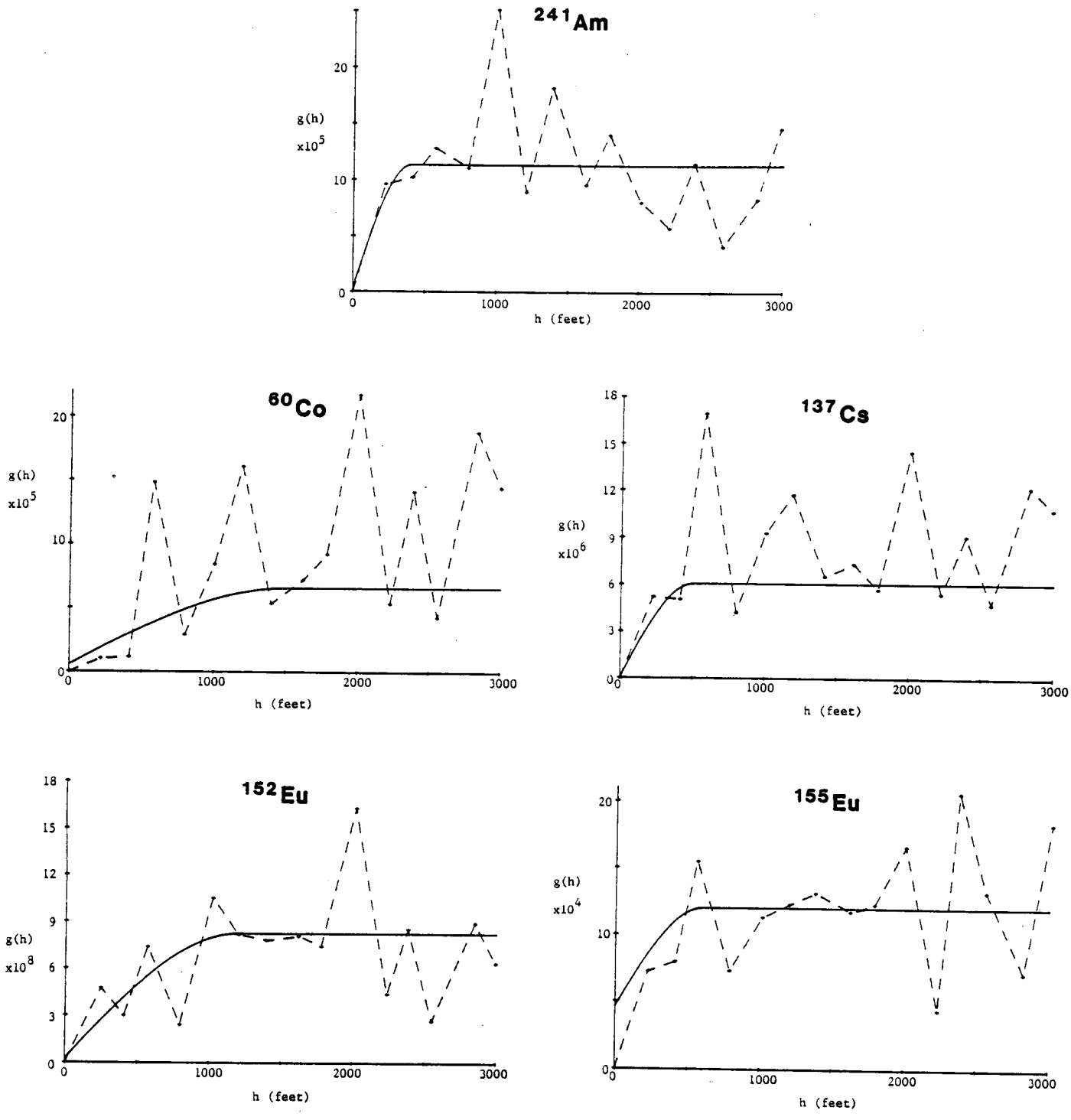

Figure 10. Sample variograms and fitted models.

desirable to confirm the kriging estimates with less sophisticated methods that are probably more robust in situations where the kriging model is not realistic. The polygons of influence method was used for this purpose with the Galileo data (McArthur and Kordas, 1983), but determining the polygons of influence in Areas 2 and 4 is prohibitively tedious because many of the sampling points are not on a regular grid. The vicinities of the Kepler and Whitney GZs were sampled with a regular pattern, however, and polygons for these regions are easily drawn (Figure 11) if a point NW of the Kepler GZ is ignored and if the other points are assumed to lie on the nodes of a regular grid (even though several points are 30 to 40 feet from their assumed locations).

The polygons of influence method is intuitively reasonable, but it does not necessarily give unbiased estimates. If the two points labeled "a" in the Whitney GZ region in Figure 11 are ignored, the remaining points form a regular 3 x 3 grid over the

Results

Table 5 shows the results of four estimation methods with the data from the Kepler and Whitney GZ areas. The estimated mean activities are presented here instead of inventories to make comparison with the data in Figures 4 to 9 easier. As expected, the arithmetic mean of the data overestimates the average activity because of the concentration of sampling points in regions of high activity. The polygons of influence estimates also tend to be high for the same reason. The unbiased means and the kriging estimates generally agree well, providing some evidence that the kriging results are reasonable.

The estimated radionuclide inventories are given in Table 6. Inventory estimates for plutonium and ^{90}Sr were derived by multiplying the ^{241}Am and ^{137}Cs estimates by the mean ratios in Table 3. The unbiased means in Table 5 were used to estimate the ^{154}Eu inventory because there were not enough data for kriging.

The initial kriging results for ^{137}Cs showed about 29 Ci in the Kepler area, 10 Ci in the Shasta area, and 11 Ci in the Whitney area. These values did not seem consistent with the data in Figure 6, which suggest that the Shasta inventory should be larger than the Whitney inventory and that the Kepler inventory is probably not three times the Shasta inventory. Table 5 tends to confirm the kriging results in the GZ regions, so it seems logical to check the kriging results outside the GZ regions. The sampling points in these outer regions are fairly uniformly distributed, and the means of the data should give nearly unbiased estimates of the true means there. These means are compared with the kriging estimates in Table 7. (Again, all the data from an area were used in estimating the mean in any territory within that area by kriging.) Kriging appears to overestimate the inventory outside these two GZ regions, and the estimates from the unbiased means were therefore used in Table 6.

TABLE 5. ESTIMATES OF MEAN ACTIVITY IN TWO GZ AREAS

	Activity (nCi/m^2)					
	^{241}Am	^{60}Co	^{137}Cs	^{152}Eu	^{154}Eu	^{155}Eu
Kepler GZ						
arithmetic mean	720	700	2,980	18,330	1,150	200
unbiased mean	310	350	1,400	8,830	610	100
polygons	330	380	1,640	9,570	680	110
kriging	350	360	1,600	8,490	--	110
Whitney GZ						
arithmetic mean	740	2,460	6,870	41,600	2,230	520
unbiased mean	320	1,620	3,890	27,100	1,380	250
polygons	560	2,080	5,570	35,200	1,870	400
kriging	280	1,940	3,120	29,800	--	250

TABLE 6. ESTIMATED INVENTORIES IN AREAS 2 AND 4

		Background Region			Above-Background Regions		
	Area	Mean (nCi/m^2)	Area ($ft^2 \times 10^6$)	Inventory (Ci)	Mean (nCi/m^2)	Area ($ft^2 \times 10^6$)	Inventory (Ci)
^{241}Am	Kepler	38	59.967	0.2	280	213.993	5.6
	Shasta	41	97.01	0.4	89	39.79	0.3
	Whitney	39	67.92	0.2	250	7.68	0.2
	Diablo	36	59.52	0.2	170	52.08	0.8
				1.0			6.9
^{238}Pu	Kepler	--	59.967	0.4	--	213.993	11.2
	Shasta	--	97.01	1.2	--	39.79	0.9
	Whitney	--	67.92	0.7	--	7.68	0.7
	Diablo	--	59.52	0.5	--	52.08	2.2
				2.8			15.0
$^{239,240}Pu$	Kepler	--	59.967	1.2	--	213.993	33.6
	Shasta	--	97.01	3.0	--	39.79	2.3
	Whitney	--	67.92	2.4	--	7.68	2.4
	Diablo	--	59.52	1.1	--	52.08	4.5
				7.7			42.8
^{60}Co	Kepler	38	53.879	0.2	180	220.081	3.7
	Shasta	23	44.84	0.1	67	91.96	0.6
	Whitney	14	29.82	0.0	380	45.78	1.6
	Diablo	17	72.88	0.1	74	38.72	0.3
				0.4			6.2
^{137}Cs	Kepler	--	--	--	430	273.96	11.0
	Shasta	--	--	--	820	136.8	10.4
	Whitney	--	--	--	570	75.6	4.0
	Diablo	--	--	--	870	111.6	9.0
				--			34.4
^{90}Sr	Kepler	--	--	--	--	273.96	14.3
	Shasta	--	--	--	--	136.8	27.0
	Whitney	--	--	--	--	75.6	11.2
	Diablo	--	--	--	--	111.6	18.0
				--			70.5
^{152}Eu	Kepler	61	257.96	1.5	8500	16.0	12.6
	Shasta	54	118.56	0.6	150	18.24	0.3
	Whitney	44	52.08	0.2	8900	23.52	19.4
	Diablo	48	104.49	0.5	540	7.11	0.4
				2.8			32.7
^{154}Eu	Kepler	83	257.96	2.0	610	16.0	0.9
	Shasta	91	136.8	1.2	--	--	--
	Whitney	82	69.84	0.5	1380	5.76	0.7
	Diablo	107	111.6	1.1	--	--	--
				4.8			1.6
^{155}Eu	Kepler	36	257.96	0.9	110	16.0	0.2
	Shasta	37	84.48	0.3	66	52.32	0.3
	Whitney	37	69.84	0.2	250	5.76	0.1
	Diablo	37	107.31	0.4	190	4.29	0.1
				1.8			0.7

TABLE 7. ^{137}Cs ESTIMATES IN THE KEPLER AND WHITNEY AREAS

	Area ($ft^2 \times 10^6$)	Mean (nCi/m^2)		Inventory (Ci)	
		unbiased	kriging	unbiased	kriging
Kepler					
GZ area	16.00	1400	1600	2.1	2.4
outside GZ	257.96	370	1130	8.9	27.0
	273.96			11.0	29.4
Whitney					
GZ area	5.76	3890	3120	2.1	1.7
outside GZ	69.84	300	1400	1.9	9.1
	75.60			4.0	10.8

Distribution Patterns

The distributions of the six radionuclides measured by *in situ* spectrometry were estimated by using kriging to interpolate the activities on a 500-foot grid of points over the entire region. There is no restriction on the number of data values when BLUEPACK is used to estimate individual points, so the data set was not partitioned as it was when inventories were estimated. Estimates for ^{154}Eu were made using a generalized polynomial covariance model, $g(h) = 5.16 \times 10^6$ for all h, fitted automatically by BLUEPACK.

After the arrays of interpolated values were generated, isopleths of activity were drawn by the NCAR subroutine CONREC (Wright, 1977). The isopleths are shown in Figures 12 through 17.

CONCLUSION

Kriging has been used to estimate radionuclide distributions since before the RIDP began (see, for example, Barnes *et al.*, 1980). The method is appealing because it takes the correlation of the data at nearby points into account to produce unbiased estimates with the smallest estimation error. However, the optimal properties of kriging depend on a statistical model that does not realistically describe the distribution of radionuclides at many places on the Nevada Test Site, and the kriging results should not be accepted blindly as being more accurate or more precise than results from other methods.

Analysis of the data from Areas 2 and 4 shows that kriging can give reasonable results even when radionuclides are concentrated around a ground zero, but it also demonstrates that problems can occur. The sample points near the GZs tend to be closely surrounded by other sample points, and kriging should give relatively small weight to

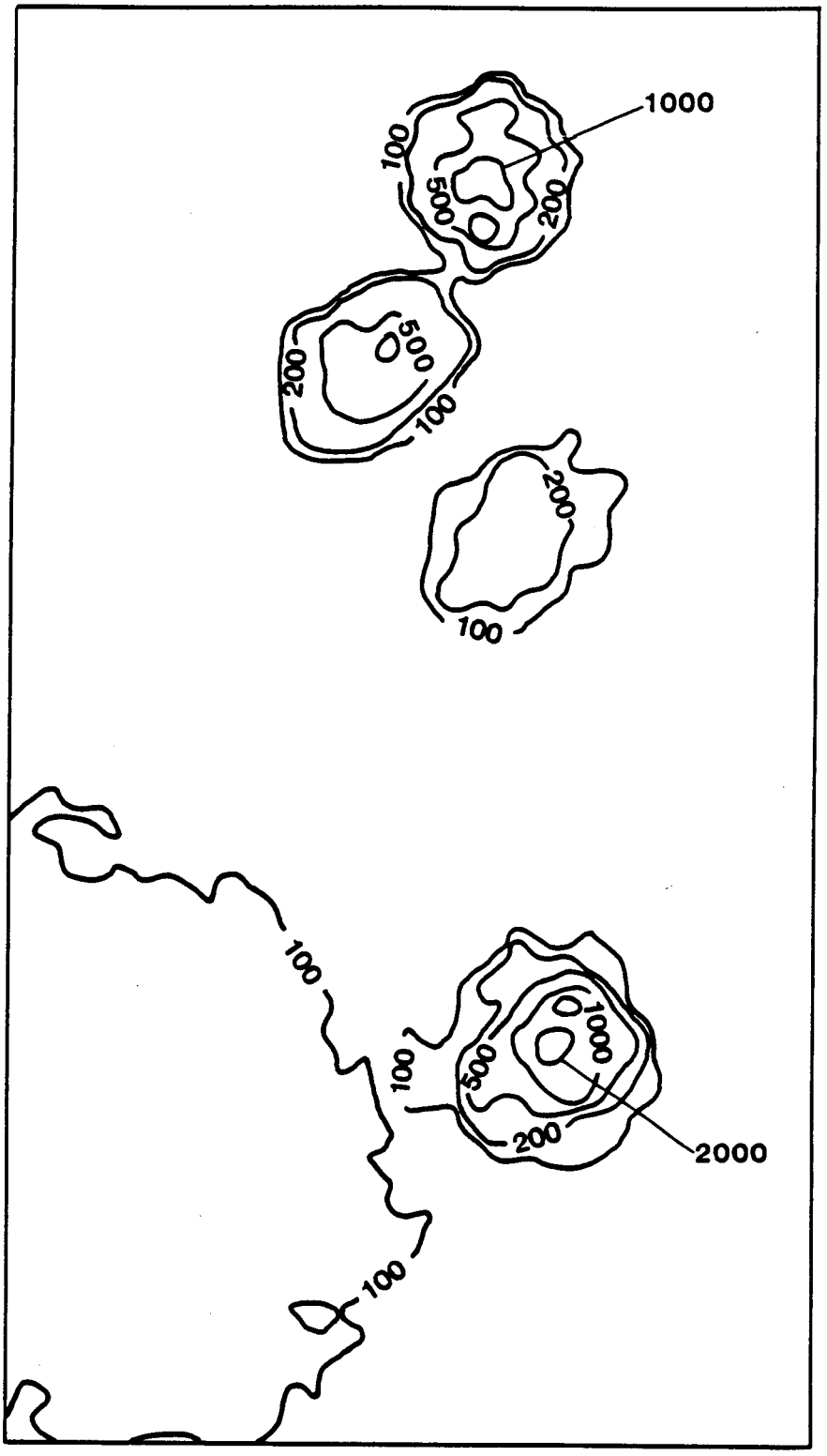

Figure 12. Isopleths of ^{241}Am activity (nCi/m^2).

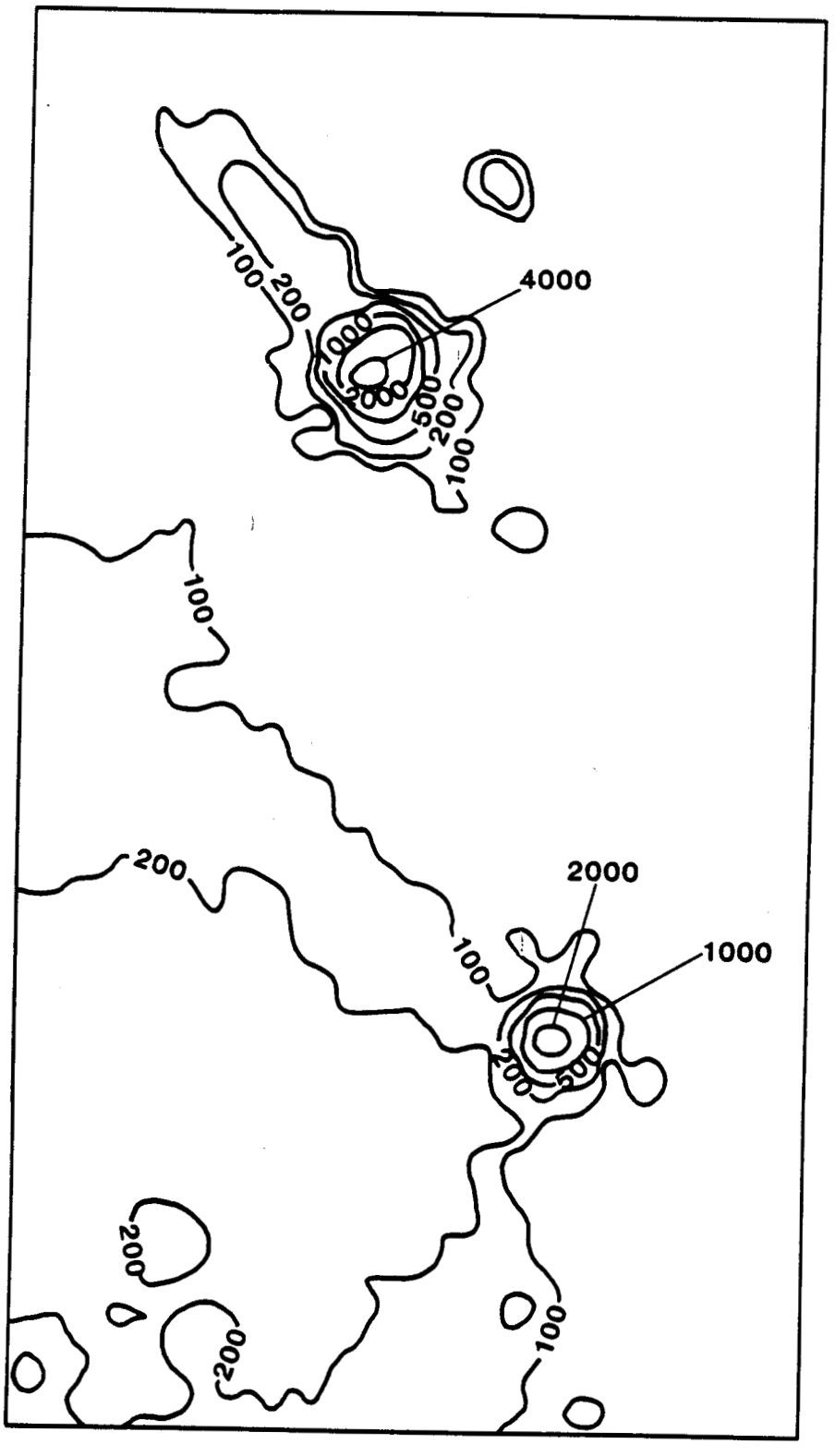

Figure 13. Isopleths of ^{60}Co activity (nCi/m^2).

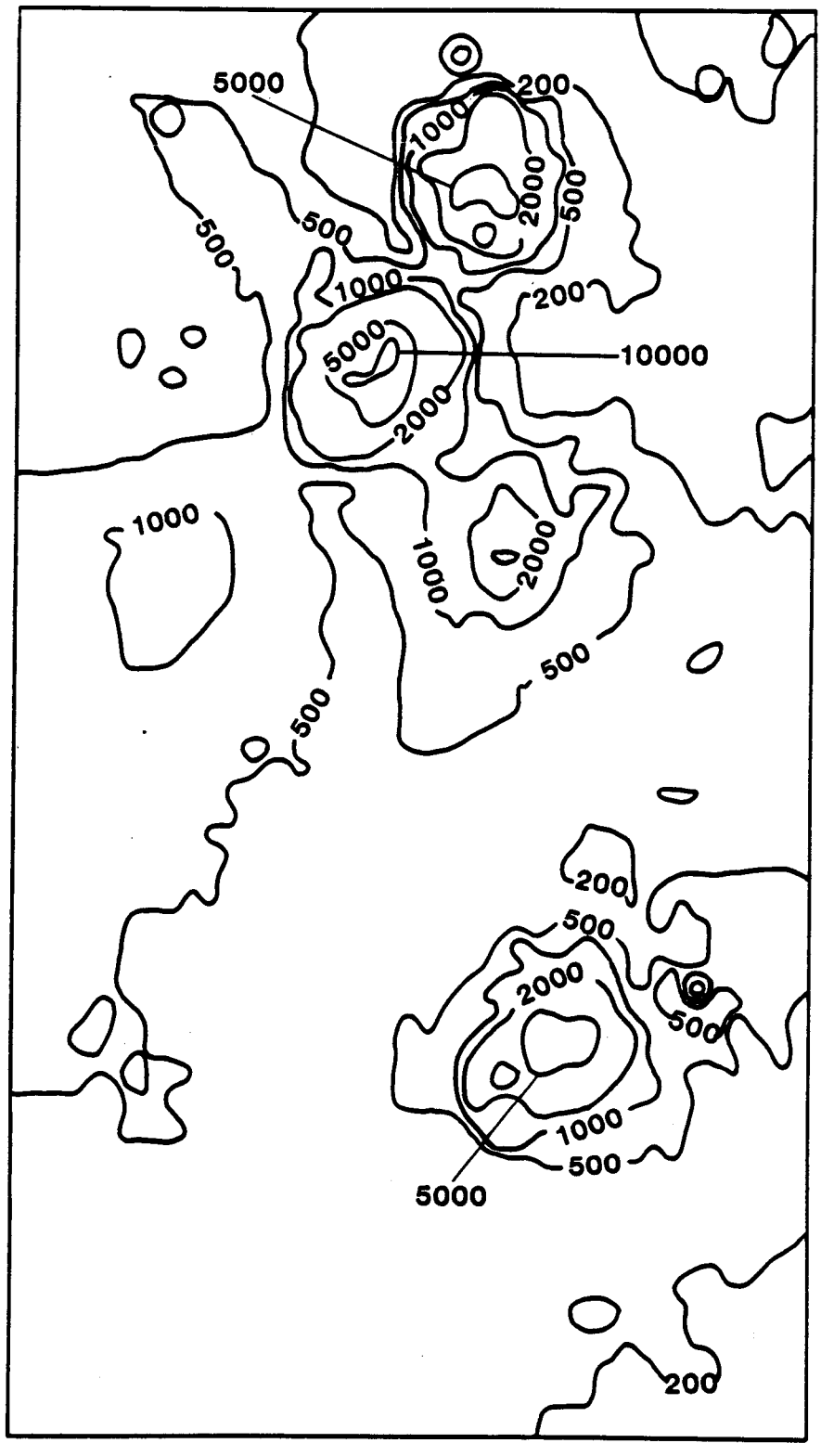

Figure 14. Isopleths of ^{137}Cs activity (nCi/m^2).

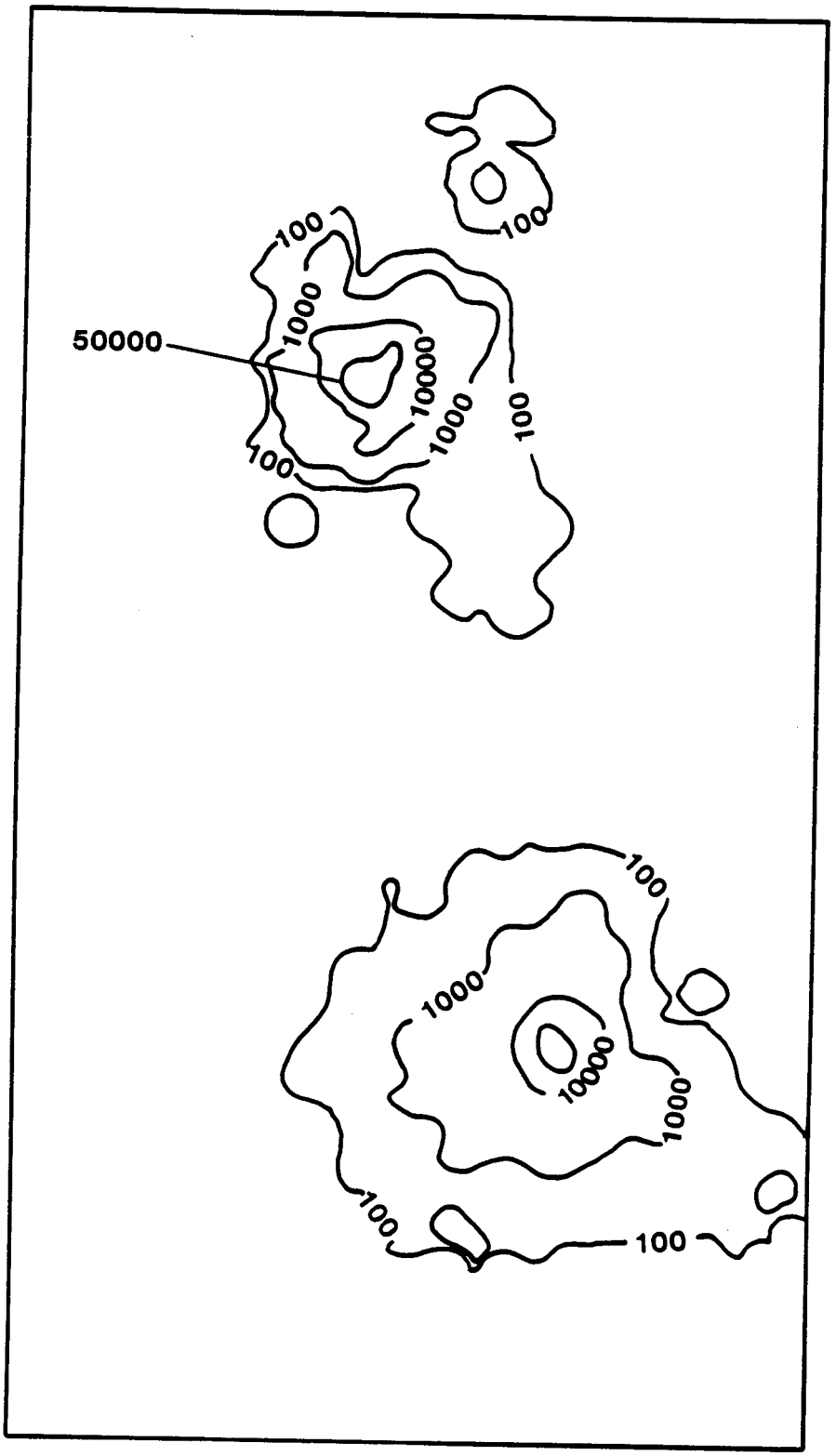

Figure 15. Isopleths of ^{152}Eu activity (nCi/m^2).

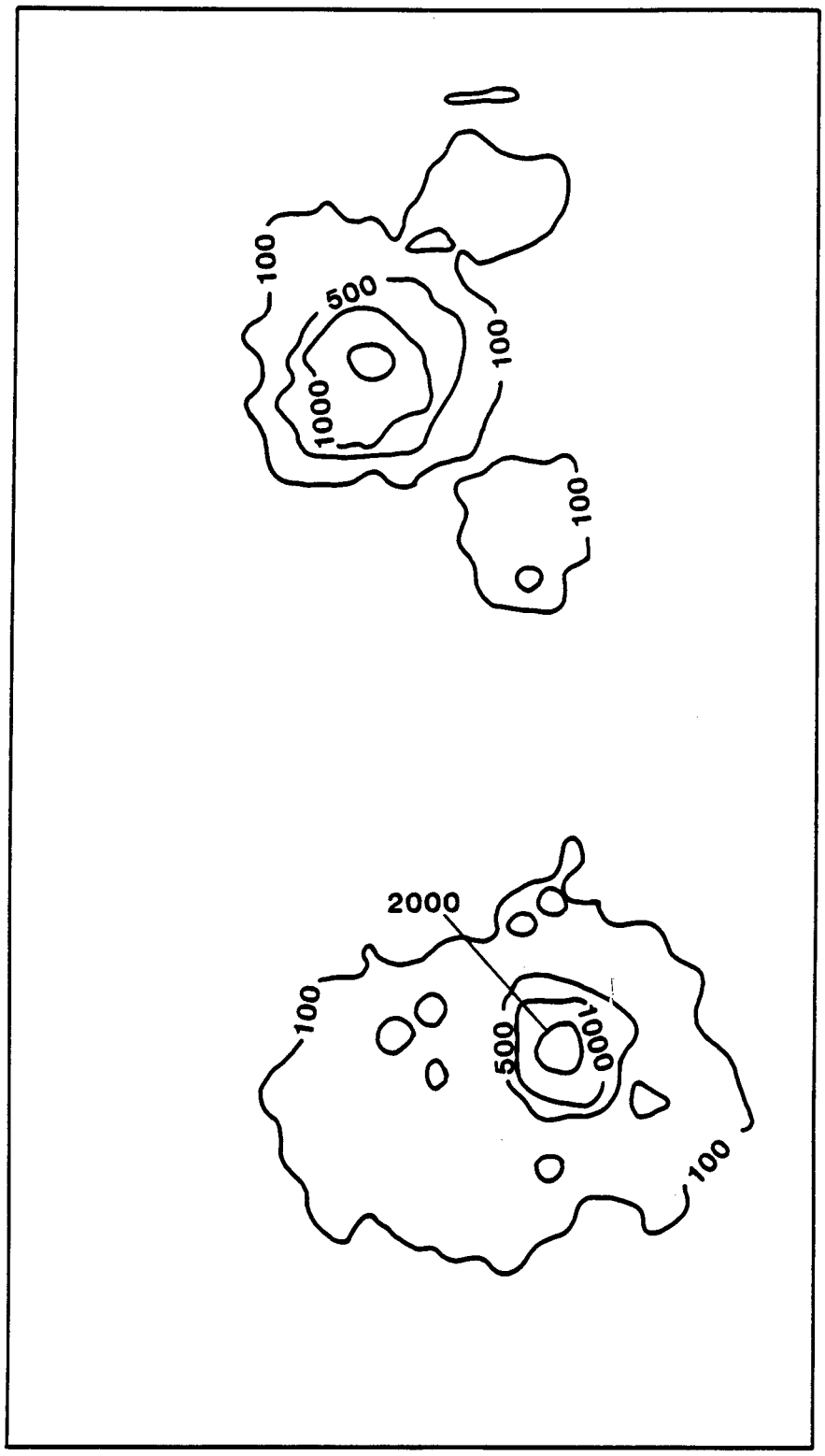

Figure 16. Isopleths of ^{154}Eu activity (nCi/m^2).

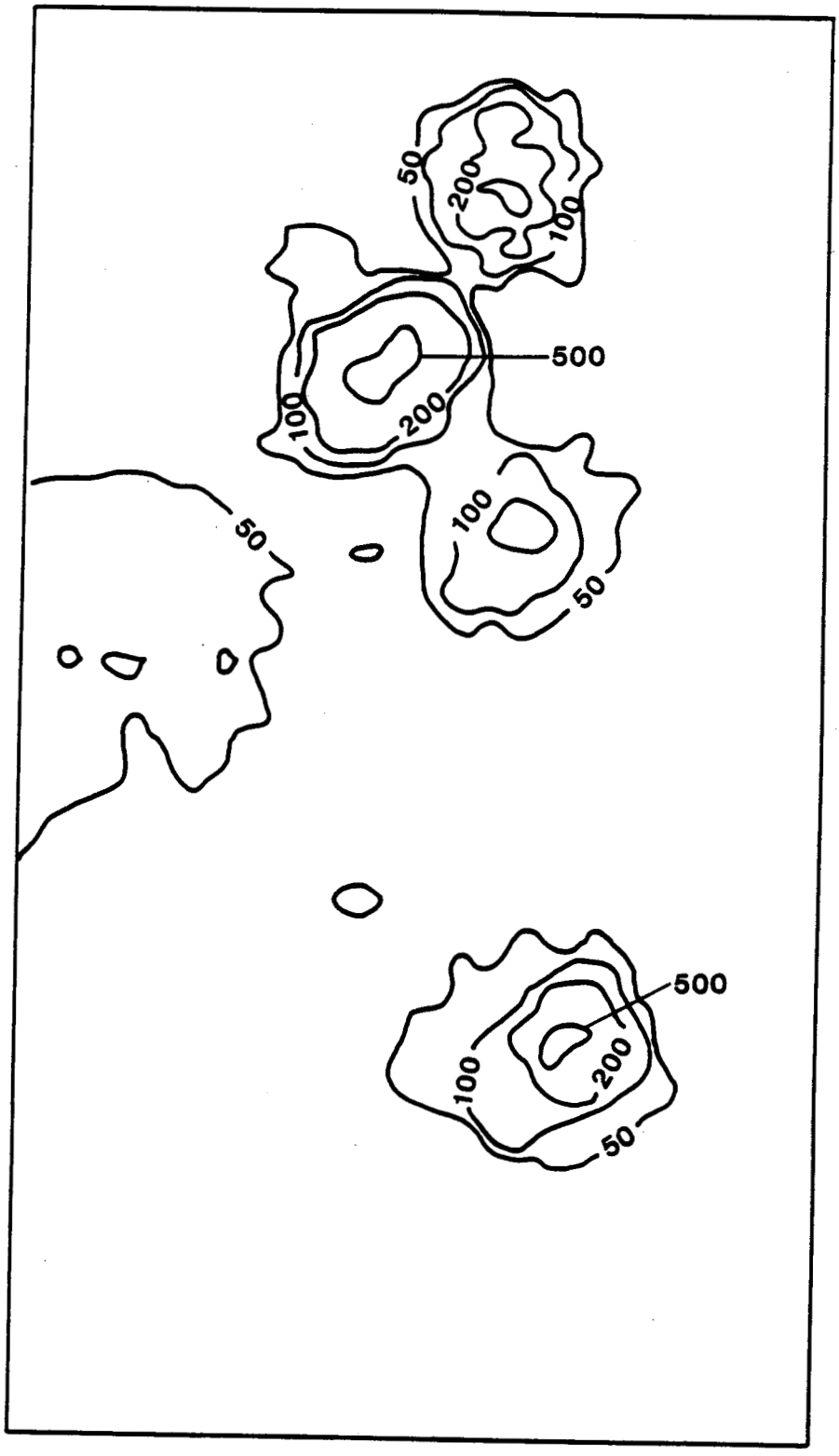

Figure 17. Isopleths of ^{155}Eu activity (nCi/m^2).

such points when estimating the mean over the entire area. With the ^{137}Cs data, however, the large values near two of the GZs were given too much weight, possibly because the wrong variogram model was used (all the variogram models were derived from very erratic sample variograms computed from relatively few data). Ideally the data from the GZ areas and the data from the outlying areas should be analyzed separately (as was done with the unbiased means), but the GZ areas are usually too small to produce enough data for a kriging analysis.

Research into the performance of kriging and other estimators with the kinds of data encountered by the RIDP is continuing. For the present, the strategy of obtaining inventory estimates by kriging, then confirming them by other methods when possible and modifying them as appropriate, seems to be the most workable.

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Appendix A: **Locations of Soil Samples**

This table gives the Nevada Grid Coordinates and original point numbers of the locations shown in Figure 3. To simplify presentation of the results, the locations have been numbered sequentially in this report. However, the original numbers will be used to identify the location in the RIDP database.

	Nevada Grid Coordinates		
Point #	E	N	Original Point #
1	660394	876041	Diablo 37
2	666819	876057	Diablo 40
3	661233	874851	Diablo 27
4	664843	874855	Diablo 31
5	661680	873810	Whitney 11
6	662071	874059	Diablo 14
7	662477	874214	Whitney 1
8	663635	874057	Diablo 18
9	662522	873820	Whitney 12
10	662451	873668	Diablo 6
11	663310	873836	Whitney 13
12	663234	873669	Diablo 8
13	662500	873031	Whitney 24
14	658507	872222	Whitney 34
15	659311	870618	Whitney 53
16	660900	870627	Whitney 55
17	660500	870229	Whitney 63
18	660025	869837	Whitney 68
19	659701	869920	Whitney 78
20	659289	869029	Whitney 80
21	660913	869027	Whitney 82
22	661710	868236	Whitney 91
23	658158	866220	Whitney 115
24	663302	866610	Whitney 110
25	664102	866612	Whitney 111
26	663399	866221	Whitney 119
27	663306	865834	Whitney 122
28	664082	865814	Whitney 123
29	664516	865411	Whitney 133
30	664464	855834	Kepler 19
31	663664	854234	Kepler 10
32	664443	854428	Kepler 2
33	664264	854234	Kepler 5
34	664462	854233	Kepler 1
35	664664	854234	Kepler 3
36	664464	854035	Kepler 4
37	665264	854234	Kepler 12
38	664462	852622	Kepler 15

Appendix B: **Radionuclide Concentrations in Soil Samples**

The depth increments are: a = 0 - 2.5 cm, b = 2.5 - 5 cm, c = 5 - 10 cm, d = 10 - 15 cm. The values in parentheses are one standard deviation in percent. Concentrations with 100% error are upper limit values. Concentrations have been omitted when none of the values for a particular radionuclide exceeded the detection limit.

Sample Pt. & Increment	Weight (g)			Concentration (pCi/g)					
	wet	dry	sieved	^{60}Co	^{137}Cs	^{152}Eu	^{154}Eu	^{155}Eu	^{241}Am
1 a	376	367	220	-- --	1.59 (5.8)	-- --	-- --	-- --	-- --
b	316	299	209	-- --	-- --	-- --	-- --	-- --	-- --
c	832	777	665	-- --	-- --	-- --	-- --	-- --	-- --
d	561	542	476	-- --	-- --	-- --	-- --	-- --	-- --
2 a	253	250	214	-- --	0.27 (20)	-- --	-- --	-- --	-- --
b	332	319	293	-- --	-- --	-- --	-- --	-- --	-- --
c	638	605	574	-- --	-- --	-- --	-- --	-- --	-- --
d	620	588	563	-- --	-- --	-- --	-- --	-- --	-- --
3 a	371	366	250	0.21 (13)	2.66 (4.6)	-- --	-- --	-- --	-- --
b	417	405	230	-- --	1.68 (5.4)	-- --	-- --	-- --	-- --
c	737	700	495	-- --	0.19 (21)	-- --	-- --	-- --	-- --
d	725	699	468	-- --	-- --	-- --	-- --	-- --	-- --
4 a	204	202	165	0.23 (12)	6.32 (4.4)	-- --	-- --	0.61 (16)	1.25 (16)
b	368	364	294	-- --	4.35 (5.0)	-- --	-- --	-- --	-- --
c	668	644	569	-- --	1.50 (6.3)	-- --	-- --	-- --	-- --
d	647	622	590	-- --	-- --	-- --	-- --	-- --	-- --
5 a	468	441	163	0.20 (14)	1.75 (3.9)	0.41 (16)	-- --	0.11 (100)	-- --
b	434	383	346	0.04 (100)	0.58 (7.4)	0.54 (12)	-- --	0.17 (41)	-- --
c	984	916	430	0.04 (100)	0.05 (100)	0.38 (14)	-- --	0.19 (34)	-- --
d	1262	1176	527	0.07 (42)	0.05 (100)	0.11 (100)	-- --	0.13 (100)	-- --
6 a	293	283	250	5.19 (4.8)	327 (4.2)	2.27 (19)	-- --	24.7 (4.7)	80.3 (4.6)
b	275	258	231	3.56 (5.2)	231 (4.2)	-- --	-- --	17.7 (4.8)	52.4 (4.8)
c	545	509	488	0.73 (8.2)	51.0 (4.2)	1.22 (14)	-- --	3.20 (7.8)	10.7 (6.8)
d	565	539	474	-- --	4.14 (4.7)	1.10 (9.2)	-- --	-- --	-- --
7 a	338	302	257	0.53 (9.7)	19.5 (1.3)	4.03 (3.3)	-- --	1.31 (11)	3.45 (9.5)
b	370	317	267	0.69 (8.5)	19.2 (1.3)	4.45 (3.0)	-- --	1.61 (6.6)	4.49 (8.2)
c	830	734	540	0.75 (7.6)	11.9 (3.0)	5.58 (2.9)	-- --	1.11 (12)	1.85 (20)
d	860	758	583	0.45 (13)	0.09 (100)	5.26 (100)	-- --	0.22 (100)	0.25 (100)
8 a	248	242	184	-- --	4.71 (4.7)	-- --	-- --	0.62 (18)	-- --
b	435	414	355	-- --	0.15 (18)	-- --	-- --	-- --	-- --
c	618	590	500	-- --	-- --	-- --	-- --	-- --	-- --
d	526	509	433	-- --	-- --	0.46 (12)	-- --	-- --	-- --
9 a	269	241	193	1.33 (6.2)	42.0 (1.0)	3.75 (3.3)	-- --	3.38 (4.2)	9.43 (8.1)
b	495	437	293	0.35 (13)	2.18 (4.1)	3.69 (3.4)	-- --	0.35 (23)	0.26 (100)
c	980	843	719	0.16 (22)	0.06 (100)	3.19 (3.7)	-- --	0.16 (100)	0.31 (100)
d	1097	933	794	0.20 (27)	0.08 (100)	2.16 (5.2)	-- --	0.19 (100)	0.23 (100)
10 a	263	263	237	0.32 (15)	12.0 (4.4)	1.80 (6.8)	-- --	1.32 (11.0)	2.31 (16)
b	317	317	277	-- --	2.46 (5.0)	1.78 (6.4)	-- --	-- --	-- --
c	461	458	368	-- --	0.86 (7.6)	1.36 (8.2)	-- --	-- --	-- --
d	621	598	505	-- --	-- --	1.61 (7.8)	-- --	-- --	-- --
11 a	369	325	285	0.94 (5.3)	53.7 (0.9)	0.94 (9.4)	-- --	5.07 (3.4)	13.0 (6.9)
b	368	316	276	0.28 (15)	11.9 (1.4)	0.88 (8.7)	-- --	1.37 (9.9)	2.76 (12)
c	1192	1134	201	0.05 (100)	1.29 (5.7)	0.84 (9.8)	-- --	0.09 (100)	0.31 (27)
d	1017	929	436	0.05 (100)	0.38 (15)	0.75 (10)	-- --	0.13 (100)	0.24 (100)

Sample Pt. & Increment	Weight (g)			Concentration (pCi/g)					
	wet	dry	sieved	^{60}Co	^{137}Cs	^{152}Eu	^{154}Eu	^{155}Eu	^{241}Am
12 a	582	582	154	2.75 (6.8)	127 (4.2)	-- --	-- --	9.86 (5.8)	28.8 (5.1)
b	303	302	189	-- --	5.29 (4.8)	-- --	-- --	0.71 (21)	-- --
c	312	309	245	-- --	0.45 (14)	-- --	-- --	-- --	-- --
d	542	538	353	-- --	-- --	-- --	-- --	-- --	-- --
13 a	425	398	282	0.12 (31)	3.31 (3.0)	0.32 (24)	-- --	0.28 (35)	-- --
b	514	462	336	0.04 (100)	0.37 (16)	0.22 (37)	-- --	0.12 (100)	-- --
c	1017	915	743	0.05 (100)	0.05 (100)	0.14 (100)	-- --	0.14 (100)	-- --
d	964	868	659	0.06 (100)	0.07 (100)	0.16 (100)	-- --	0.18 (100)	-- --
14 a	362	337	233	3.99 (2.1)	14.0 (1.3)	0.42 (19)	-- --	1.03 (14)	0.85 (35)
b	472	439	209	1.18 (4.0)	3.98 (2.2)	0.11 (100)	-- --	0.12 (100)	0.22 (100)
c	1015	922	662	0.24 (15)	0.82 (7.5)	0.26 (21)	-- --	0.08 (100)	0.08 (100)
d	1475	1379	276	0.04 (100)	0.28 (23)	0.10 (100)	-- --	0.12 (100)	0.22 (100)
15 a	344	284	236	1.31 (5.1)	0.78 (12)	17.1 (1.1)	0.76 (15)	-- --	-- --
b	356	266	236	1.25 (4.5)	0.19 (28)	14.8 (1.1)	0.55 (21)	-- --	-- --
c	936	752	606	1.51 (4.6)	0.18 (35)	19.5 (1.5)	0.76 (22)	-- --	-- --
d	814	679	580	2.65 (3.7)	0.12 (100)	36.4 (1.0)	1.97 (12)	-- --	-- --
16 a	538	535	201	2.62 (2.6)	15.1 (1.3)	20.6 (1.2)	1.23 (11)	1.28 (9.6)	0.87 (23)
b	445	430	241	1.32 (8.1)	2.25 (3.4)	20.3 (0.9)	0.84 (13)	0.16 (100)	0.27 (100)
c	778	749	353	1.06 (4.9)	0.24 (26)	17.0 (1.4)	0.67 (25)	0.21 (32)	0.09 (100)
d	831	798	317	0.81 (5.9)	0.06 (100)	13.4 (1.7)	0.48 (28)	0.15 (100)	0.27 (100)
17 a	370	342	274	27.5 (1.0)	100 (1.0)	294 (0.5)	19.2 (2.6)	7.30 (15)	7.83 (26)
b	388	352	291	27.8 (1.0)	107 (0.9)	280 (0.6)	17.2 (2.7)	7.55 (6.1)	12.2 (11)
c	968	909	481	33.1 (0.9)	123 (0.9)	292 (0.7)	19.2 (3.3)	10.3 (16)	8.29 (44)
d	1009	939	562	25.5 (2.9)	80.0 (2.7)	259 (0.8)	15.9 (5.3)	6.13 (22)	4.86 (42)
18 a	301	282	181	15.7 (1.1)	306 (0.8)	123 (1.1)	6.80 (7.9)	11.3 (9.1)	20.7 (19)
b	458	424	258	17.3 (1.0)	64.1 (1.0)	235 (0.6)	11.6 (3.8)	3.54 (22)	3.99 (40)
c	823	758	469	14.3 (1.1)	15.1 (1.7)	221 (0.6)	10.7 (4.5)	0.24 (100)	0.20 (100)
d	987	929	444	7.29 (1.7)	12.1 (3.6)	118 (1.0)	5.05 (7.4)	0.71 (50)	0.46 (100)
19 a	254	242	162	36.1 (1.0)	135 (1.0)	419 (0.5)	27.4 (2.3)	11.0 (4.7)	14.5 (12)
b	454	425	240	29.9 (1.1)	9.84 (4.1)	490 (0.5)	28.4 (2.9)	0.55 (100)	0.90 (100)
c	1028	952	595	29.8 (1.1)	1.06 (22)	473 (0.6)	23.8 (2.9)	0.76 (100)	1.39 (100)
d	947	847	699	22.3 (2.0)	0.29 (100)	321 (0.7)	14.7 (4.8)	0.62 (100)	0.67 (100)
20 a	495	484	227	10.9 (2.5)	101 (0.9)	39.4 (1.0)	2.59 (7.9)	7.64 (4.8)	5.68 (14)
b	437	406	277	4.58 (2.1)	28.3 (1.0)	35.0 (0.9)	2.03 (8.0)	2.03 (7.0)	1.22 (40)
c	964	907	420	2.26 (3.0)	4.06 (3.0)	31.8 (1.1)	1.56 (14)	0.21 (41)	0.11 (100)
d	855	807	241	1.74 (4.0)	2.36 (4.7)	26.4 (1.4)	1.09 (16)	0.18 (100)	0.32 (100)
21 a	383	368	239	7.07 (1.7)	77.4 (0.9)	37.9 (0.8)	2.44 (7.0)	6.38 (4.7)	6.09 (8.8)
b	507	474	308	2.26 (3.6)	16.4 (1.3)	21.4 (1.2)	0.97 (17)	1.36 (9.6)	1.48 (18)
c	917	848	591	1.04 (5.7)	1.47 (8.3)	18.1 (1.3)	0.81 (18)	0.23 (100)	0.44 (100)
d	1179	1116	522	0.80 (8.7)	0.62 (15)	12.1 (1.7)	-- --	0.22 (100)	0.24 (100)
22 a	452	428	251	0.78 (8.3)	7.35 (2.4)	2.92 (3.1)	-- --	0.61 (20)	-- --
b	391	367	231	0.26 (13)	2.35 (2.9)	1.14 (7.4)	-- --	0.23 (27)	-- --
c	1038	965	638	0.15 (21)	1.54 (4.3)	0.82 (8.3)	-- --	0.25 (49)	-- --
d	1178	1109	586	0.04 (100)	0.10 (33)	0.47 (15)	-- --	0.12 (100)	-- --
23 a	389	364	250	1.70 (3.6)	13.5 (1.4)	1.69 (6.0)	-- --	1.10 (8.8)	0.86 (24)
b	489	449	319	1.00 (5.4)	6.32 (1.8)	0.74 (11)	-- --	0.63 (15)	-- --
c	571	466	410	0.19 (20)	1.41 (5.3)	0.30 (43)	-- --	0.17 (100)	0.34 (100)
d	789	720	362	0.06 (100)	0.53 (20)	0.15 (100)	-- --	0.18 (100)	0.22 (100)
24 a	451	426	266	1.15 (5.0)	33.2 (1.1)	3.21 (4.0)	-- --	2.75 (4.7)	5.26 (9.3)
b	510	472	320	0.48 (9.4)	5.41 (2.2)	2.38 (4.4)	0.16 (52)	0.55 (16)	0.62 (37)
c	932	861	560	0.17 (24)	0.41 (12)	1.89 (4.8)	-- --	0.18 (100)	0.37 (100)
d	936	860	621	0.19 (26)	0.07 (100)	1.60 (8.1)	-- --	0.18 (100)	0.22 (100)

Sample Pt. & Increment	Weight (g)			Concentration (pCi/g)					
	wet	dry	sieved	^{60}Co	^{137}Cs	^{152}Eu	^{154}Eu	^{155}Eu	^{241}Am
25 a	425	409	300	0.30 (12)	5.37 (1.9)	0.60 (11)	-- --	0.45 (18)	0.86 (25)
b	410	385	296	0.09 (31)	0.74 (6.2)	0.66 (9.6)	-- --	0.11 (100)	0.20 (100)
c	982	909	637	0.04 (100)	0.04 (100)	0.33 (16)	-- --	0.24 (44)	0.07 (100)
d	862	792	624	0.04 (100)	0.12 (37)	0.35 (21)	-- --	0.12 (100)	0.23 (100)
26 a	460	431	357	2.34 (3.7)	121 (0.8)	2.96 (4.3)	-- --	9.08 (2.7)	21.5 (6.7)
b	482	450	307	0.19 (15)	2.24 (3.2)	2.53 (3.2)	-- --	0.11 (100)	0.20 (100)

Appendix C: **Quality Assurance for Measurements of Soil Radioactivity**

by E.H. Essington (Los Alamos National Laboratory)
and S.W. Mead (Lawrence Livermore National Laboratory)

Radiochemical analyses and gamma spectrometric measurements of the soil samples collected for the RIDP are conducted by the REECo Analytical Laboratory. To ensure the reliability of these analyses, a set of quality assurance (QA) procedures was in effect when the soil samples from Areas 2 and 4 were analyzed. These procedures included analysis of replicate aliquots from the same sample, analysis of independently-calibrated reference blinds for a related program, and duplicate gamma spectrometric measurements of samples by LLNL.

Although these efforts support the general adequacy of both the gamma measurements and the radiochemical analyses performed by REECo, several inconsistencies were noted. It is often difficult to determine whether such inconsistencies reflect the presence of a few highly radioactive particles (the "hot particle" problem) or constitute errors in technique or data transcription. To try to resolve the uncertainties and provide further assurance of the reliability of the data, a series of samples from Areas 2 and 4 was reanalyzed by two independent laboratories.

Five representative soil samples were selected from those already analyzed by REECo and submitted to Los Alamos National Laboratory and EAL Corporation. Both laboratories withdrew and analyzed three aliquots from each sample, as is typically done by REECo. The gamma-emitting radionuclides were first measured on the dry soil aliquot and then the $^{239,240}Pu$, ^{238}Pu and ^{90}Sr were chemically separated from the dissolved sample and determined by alpha- or beta-particle counting. REECo conducted gamma spectrometric measurements first on the dry soil and then on the solution derived from the dissolved soil. EAL analyzed for ^{241}Am by the radiochemical method. Appropriate results have been decay-corrected to January 1, 1985.

Results of the radiochemical analyses are shown in Table C-1, while results of the gamma spectrometric measurements are shown in Tables C-2 through C-4. The aliquot numbers in these tables refer only to the 10g aliquots analyzed by REECo; the sample point number is given for reference to the coordinate data in Appendix A.

This supplementary QA program permits a comparison of the results obtained by four laboratories. A general review of the data shows reasonably good agreement among the laboratories in most instances. Coefficients of variation are generally less than 0.2 except in cases involving low levels of radioactivity. Several inconsistencies have been noted, however, in the results reported by REECo, particularly for radionuclides whose

measurement involves chemical separation. These inconsistencies may be characterized as "high variability" or as high or low "bias."

The high variability cases generally involve a group of measurements that contains apparent "outliers," *i.e.*, one or two of the replicate measurements of the same sample by a single laboratory are considerably different from the remaining measurements. Such variability is evident, *e.g.*, in REECo's measurements of plutonium in Sample 18576 and 18791 and of ^{90}Sr in Samples 18735 and 18791. As suggested above, such variability may occur because the original sample contains a few hot particles that find their way non-uniformly into the various aliquots. However, it does not appear that all the variability can be explained on this basis because some of the outliers have low values. High variability may also occur because REECo, in an attempt to keep activity levels in the laboratory low, counts final solution aliquots that represent smaller samples than those used by the other laboratories. A consideration of REECo's counting statistics suggests that this procedural difference is also unable to account for all the observed variability.

A few indications of a significant bias, *i.e.*, an inconsistent mean value, were also noted. The means of the plutonium and ^{90}Sr obtained by two laboratories (*e.g.*, REECo and EAL or REECo and Los Alamos) were evaluated statistically to determine if significant differences (0.975 level of significance) existed (Bethea *et al.*, 1985). The test revealed that REECo consistently reported low values only for Sample 19630. A considerable bias is also apparent in the REECo results for $^{239,240}Pu$ in Sample 18576 even if the two high outliers are neglected.

The biases noted above for REECo's plutonium and ^{90}Sr measurements of samples from Library Number 19630 are a result of consistently low measurements. A possible cause is a loss of material in the dissolution step, as is suggested by many of the gamma-spectrometry results for these samples (Tables C-2 and C-3). The loss of gamma emitters during dissolution is not in itself a problem, since the activity of these radionuclides can be accurately measured before dissolution. Such a loss serves primarily as an indication that radionuclides for which radiochemistry is required (such as ^{90}Sr) may also have been lost during the dissolution process. Because we have observed other instances of such losses, REECo is investigating the dissolution procedure and possible improvements.

In spite of some outliers and biases, the principal result of this intercomparison is a confirmation of generally accurate measurements by all the laboratories involved. Because the RIDP uses the soil radioactivity data as averaged values of many measurements, and because the objectives of the program specify a final inventory determination to within a factor of two (Kordas and Anspaugh, 1982), we believe that the REECo data are satisfactory for RIDP purposes.

Although the measurements examined in this QA investigation were found to be

TABLE C-1. QUALITY ASSURANCE RESULTS FOR $^{239,240}Pu$, ^{238}Pu, AND ^{90}Sr

Sample Point	Library Number	REECo Aliquot Number	Activity (pCi/g) $^{239,240}Pu$ REECo	$^{239,240}Pu$ Los Alamos	$^{239,240}Pu$ EAL	^{238}Pu REECo	^{238}Pu Los Alamos	^{238}Pu EAL	^{90}Sr REECo	^{90}Sr Los Alamos	^{90}Sr EAL
36	18576	60523	1250. (11)*			--†			296. (7)		
		67689	1160. (8)			--			365. (7)		
		62623	580. (8)	477. (3)	505. (2)	150. (8)	131. (3)	152. (2)	442. (2)	401. (4)	421. (4)
		62624	520. (6)	450. (3)	464. (3)	145. (6)	118. (3)	125. (3)	354. (2)	403. (3)	373. (4)
		62625	520. (6)	418. (3)	527. (3)	145. (6)	114. (3)	137. (3)	393. (2)	405. (4)	417. (4)
	Mean	(± 1 s.d.)	806. ± 366.	448. ± 30.	499. ± 32.	147. ± 3	121. ± 9	138. ± 14.	370. ± 54.	403. ± 2.	404. ± 27.
11	18735	61577	70.0 (6)			34.7 (7)			128. (3)		
		61578	77.0 (6)			39.1 (7)			224. (2)		
		61579	77.7 (6)			39.5 (6)			161. (3)		

TABLE C-2. QUALITY ASSURANCE RESULTS FOR ^{241}Am AND ^{137}Cs

Sample Point	Library Number	REECo Aliquot Number	Activity (pCi/g) ^{241}Am REECo Dry	^{241}Am REECo Solution	^{241}Am LLNL	^{241}Am Los Alamos	^{241}Am EAL	^{137}Cs REECo Dry	^{137}Cs REECo Solution	^{137}Cs LLNL	^{137}Cs Los Alamos	^{137}Cs EAL
36	18576	60052	78.8 (8)*		50.9 (10)			259. (3)		257. (1)		
		60523						260. (4)				
		61801						16.4 (5)				
		69887	60.1 (6)					193. (4)				
		69891						249. (5)				
		62623	79.0 (4)	92.3 (8)		56.8 (1)	77.0 (4)	290. (4)	278. (4)		253. (1)	259. (1)
		62624	72.6 (5)	87.8 (8)		57.7 (1)	73.0 (4)	280. (4)	235. (4)		244. (1)	261. (1)
		62625	76.0 (5)	74.6 (9)		77.5 (1)	74.3 (4)	285. (4)	217. (4)		243. (1)	259. (1)
	Mean	(± 1 s.d.)	73.3 ± 7.8	84.9 ± 9.2		64.0 ± 11.7	74.8 ± 2.0	229. ± 91.	243. ± 31.		247. ± 6.	260. ± 1.
11	18735	60211	16.1 (9)		13.0 (7)			52.0 (4)		51.0 (1)		
		61577	14.6 (8)	--†				48.8 (4)	150. (5)			
		61578	13.5 (8)	--				45.3 (4)	52.5 (5)			
		61579	13.8 (8)	27.2 (15)				50.7 (4)	55.7 (5)			
		62629	14.7 (8)	--		12.9 (3)	17.8 (5)	46.3 (4)	20.2 (6)		47.3 (1)	56.8 (1)
		62630	13.7 (8)	--		12.2 (3)	17.4 (4)	48.4 (4)	18.3 (6)		48.6 (1)	51.9 (1)
		62631	14.8 (8)	--		12.4 (3)	17.3 (5)	45.6 (4)	19.5 (7)		46.8 (2)	53.2 (1)
	Mean	(± 1 s.d.)	14.5 ± 6.2			12.5 ± 0.4	17.5 ± 0.3	48.2 ± 2.6	52.7 ± 50.6		47.6 ± 0.9	54.0 ± 2.5
26	18791	60267	--		21.5 (7)			--		116. (1)		
		61586	25.3 (6)	--				109. (4)	132. (5)			
		61587	25.1 (5)	--				112. (4)	102. (5)			
		61588	29.9 (5)	--				138. (4)	115. (5)			
		62647	23.7 (10)	42.4 (13)		23.3 (2)	22.3 (4)	116. (4)	109. (5)		112. (1)	125. (1)
		62648	22.0 (10)	20.4 (12)		23.9 (2)	32.4 (4)	106. (4)	52.6 (5)		114. (1)	135. (1)
		62649	25.5 (9)	18.0 (14)		23.7 (2)	30.0 (4)	115. (4)	59.8 (5)		113. (1)	122. (1)
	Mean	(± 1 s.d.)	25.3 ± 2.6	26.9 ± 13.4		23.6 ± 0.3	28.2 ± 5.3	116. ± 11.	95.1 ± 31.9		113. ± 1.	127. ± 7.
28	18799	60275	5.56 (13)	--	4.02 (9)			19.7 (4)		19.3 (1)		
		62650	--	--		6.26 (3)	7.75 (3)	19.2 (5)	9.87 (10)		18.3 (2)	20.9 (1)
		62651	--	--		3.80 (6)	5.18 (2)	19.9 (5)	10.6 (9)		18.6 (2)	21.2 (1)
		62652	5.05 (19)	--		4.23 (6)	4.73 (6)	19.5 (5)	8.17 (10)		18.9 (2)	19.6 (2)
	Mean	(± 1 s.d.)	5.30 ± 0.36			4.76 ± 1.31	5.89 ± 1.63	19.6 ± 0.3	9.55 ± 1.25		18.6 ± 0.3	20.6 ± 0.9
6	19630	60993	80.3 (5)					312. (4)				
		62656	80.8 (6)	39.3 (9)		71.6 (1)	89.2 (3)	306. (4)	128. (5)		297. (1)	372. (1)
		62657	83.7 (6)	31.8 (9)		70.2 (1)	90.5 (3)	311. (4)	88.1 (5)		296. (1)	327. (1)
		62658	80.2 (6)	50.0 (8)		73.0 (1)	91.0 (2)	311. (4)	124. (5)		298. (1)	306. (1)
	Mean	(± 1 s.d.)	81.2 ± 1.7	40.4 ± 9.1		71.6 ± 1.4	90.2 ± 0.9	310. ± 3.	113. ± 22.		297. ± 1.	335. ± 34.

* Numbers in parentheses are counting errors (1 s.d.) in percent.

† A "--" indicates a sample was analyzed but results were below detection or were not reported.
A blank entry indicates the sample was not analyzed.

TABLE C-3. QUALITY ASSURANCE RESULTS FOR ^{60}Co AND ^{152}Eu

Sample Point	Library Number	REECo Aliquot Number	Activity (pCi/g) ^{60}Co REECo Dry	^{60}Co REECo Solution	^{60}Co LLNL	^{60}Co Los Alamos	^{60}Co EAL	^{152}Eu REECo Dry	^{152}Eu REECo Solution	^{152}Eu LLNL	^{152}Eu Los Alamos	^{152}Eu EAL
36	18576	60052	22.6 (4)*		22.7 (1)			218. (4)		232. (1)		
		60523	22.5 (4)					190. (4)				
		61801	6.61 (5)					172. (4)				
		69887	21.8 (5)					149. (4)				
		69891	21.4 (9)					171. (5)				
		62623	24.9 (5)	26.4 (6)		21.7 (4)	23.2 (2)	211. (4)	236. (5)		221. (1)	230. (1)
		62624	25.1 (5)	20.9 (7)		20.5 (5)	21.7 (2)	209. (4)	218. (5)		218. (1)	229. (1)
		62625	24.0 (5)	21.2 (7)		20.1 (5)	22.6 (2)	209. (4)	207. (5)		218. (1)	238. (1)
	Mean	(± 1 s.d.)	21.1 ± 6.0	22.8 ± 3.1		20.8 ± 0.8	22.5 ± 0.8	191. ± 25.	220. ± 15.		219. ± 2.	232. ± 4.9
11	18735	60211	0.63 (14)		0.70 (5)			0.89 (21)		0.84 (9)		
		61577	--†	--				--	--			
		61578	--	--				--	--			
		61579	--	--				--	--			
		62629	0.86 (15)	--		0.75 (37)	0.73 (8)	--	--		<0.75	0.81 (18)
		62630	0.73 (20)	--		0.62 (49)	0.93 (12)	--	--		<0.75	0.61 (27)
		62631	0.85 (18)	--		1.64 (16)	0.76 (13)	--	--		1.77 (30)	0.73 (22)
	Mean	(± 1 s.d.)	0.77 ± 0.11	--		1.00 ± 0.56	0.81 ± 0.11					0.72 ± 0.10
26	18791	60267	--		1.80 (4)			--		2.63 (4)		
		61586	1.91 (11)	--				--	--			
		61587	1.80 (10)	--				--	--			
		61588	2.47 (8)	--				1.81 (19)	--			
		62647	1.89 (17)	--		1.80 (21)	2.08 (3)	--	--		2.05 (33)	2.70 (6)
		62648	1.52 (17)	2.50 (19)		2.45 (15)	2.51 (4)	--	--		1.28 (52)	3.13 (7)
		62649	1.99 (16)	2.43 (18)		2.04 (20)	1.98 (7)	2.87 (17)	--		2.16 (20	2.55 (14)
	Mean	(± 1 s.d.)	1.93 ± 0.31	2.46 ± 0.05		2.10 ± 0.33	2.19 ± 0.28	2.34 ± 0.75			1.83 ± 0.48	2.79 ± 0.30
28	18799	60275	0.30 (16)		0.30 (11)			--		0.86 (7)		
		62650	--	--		<0.38	0.42 (9)	--	--		0.73 (46)	1.00 (9)
		62651	--	--		0.42 (54)	0.29 (22)	--	--		1.02 (35)	1.35 (10)
		62652	--	--		<0.43	0.30 (44)	--	--		<0.57	0.70 (33)
	Mean	(± 1 s.d.)					0.34 ± 0.07				0.88 ± 0.20	1.02 ± 0.33
6	19630	60993	3.50 (5)					2.04 (19)				
		62656	3.11 (11)	3.72 (17)		3.81 (14)	4.92 (3)	--	--		<1.6	1.57 (32)
		62657	3.90 (9)	4.35 (14)		4.33 (12)	4.84 (5)	--	--		<1.6	<1.9
		62658	4.12 (9)	4.35 (14)		3.22 (19)	3.88 (5)	--	--		3.51 (32)	1.56 (39)
	Mean	(± 1 s.d.)	3.66 ± 0.45	4.14 ± 0.36		3.79 ± 0.56	4.55 ± 0.59					1.56 ± 0.01

* Numbers in parentheses are counting errors (1 s.d.) in percent.

† A "--" indicates a sample was analyzed but results were below detection or were not reported. A blank entry indicates the sample was not analyzed.

TABLE C-4. QUALITY ASSURANCE RESULTS FOR ^{154}Eu AND ^{155}Eu

Sample Point	Library Number	REECo Aliquot Number	Activity (pCi/g) ^{154}Eu REECo Dry	^{154}Eu REECo Solution	^{154}Eu LLNL	^{154}Eu Los Alamos	^{154}Eu EAL	^{155}Eu REECo Dry	^{155}Eu REECo Solution	^{155}Eu LLNL	^{155}Eu Los Alamos	^{155}Eu EAL
36	18576	60052	13.5 (4)*		14.0 (4)			-- †		11.7 (6)		
		60523	13.3 (5)					10.0 (6)				
		61801	20.5 (8)									
		69887						17.1 (9)				
		69891										
		62623	17.2 (7)	--		9.23 (13)	15.2 (6)	16.7 (6)	--		9.28 (4)	11.8 (6)
		62624	13.9 (9)	--		9.32 (13)	14.3 (6)	9.65 (10)	--		7.70 (5)	11.7 (6)
		62625	16.5 (8)	11.7 (21)		10.7 (11)	14.0 (6)	11.8 (8)	--		8.20 (4)	13.2 (5)
	Mean	(± 1 s.d.)	15.8 ± 2.8			9.75 ± 0.82	14.5 ± 0.6	13.0 ± 3.6			8.39 ± 0.81	12.2 ±0.84
11	18735	60211	--		--			4.14 (10)		3.66 (3)		
		61577	--	--				4.15 (9)	9.25 (20)			
		61578	--	--				3.77 (10)	--			
		61579	--	--				3.70 (10)	--			
		62629	--	--		0.68 (58)	<0.25	3.45 (11)	--		2.48 (6)	4.68 (3)
		62630	--	--		<0.70	<0.54	3.71 (11)	--		2.62 (6)	3.95 (6)
		62631	--	--		1.09 (46)	<0.52	2.86 (14)	--		2.66 (7)	3.92 (6)
	Mean	(± 1 s.d.)				0.88 ± 0.29		3.68 ± 0.44			2.59 ± 0.09	4.18 ± 0.43
26	18791	60267	--		--			--		6.79 (3)		
		61586	--	--				6.92 (8)	--			
		61587	--	--				7.10 (8)	--			
		61588	--	--				8.68 (6)	--			
		62647	--	--		<0.90	<0.24	5.94 (10)	10.9 (17)		5.45 (4)	8.51 (3)
		62648	--	--		<0.87	<0.33	5.78 (10)	9.25 (15)		5.36 (4)	9.45 (4)
		62649	--	--		<0.84	<0.53	7.03 (10)	7.49 (19)		5.16 (4)	8.11 (4)
	Mean	(± 1 s.d.)						6.91 ± 1.04	9.21 ± 1.71		5.32 ± 0.15	8.69 ± 0.69
28	18799	60275	--		--			--		1.31 (6)		
		62650	--	--		<0.65	<0.25	--	--		1.12 (11)	1.66 (7)
		62651	--	--		<0.55	<0.37	--	--		1.32 (10)	1.75 (10)
		62652	--	--		<0.60	<0.50	--	--		0.84 (15)	1.35 (15)
	Mean	(± 1 s.d.)									1.09 ± 0.24	1.59 ± 0.21
6	19630	60993	--					19.1 (5)				
		62656	--	--		<1.2	<0.45	17.0 (6)	8.67 (19)		13.4 (2)	25.2 (2)
		62657	--	--		<1.2	<0.68	15.5 (6)	6.80 (20)		14.2 (2)	22.3 (3)
		62658	--	--		<1.3	<0.76	15.3 (6)	8.00 (19)		14.1 (2)	20.4 (3)
	Mean	(± 1 s.d.)						16.7 ± 1.8	7.82 ± 0.95		13.9 ± 0.44	22.6 ± 2.4

* Numbers in parentheses are counting errors (1 s.d.) in percent.

† A "--" indicates a sample was analyzed but results were below detection or were not reported.
A blank entry indicates the sample was not analyzed.

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